Volume 4, Issue 1

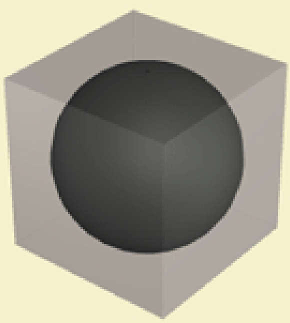
Design Notes...

Burst Charges

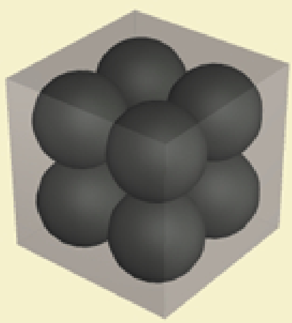
Introduction:
Unlike lift charges, there is no simple rule of thumb for finding the proper break charge for a given size shell. The type of burst charge will vary depending on the volume of space available for it inside the shell. A 3" shell has far less volume than a 6" shell, thus a stronger burst charge is needed for it. Even a 6" ring shell has considerably more volume available to the burst charge than a 6" double petal effect, due to the space occupied by the stars. So even shells of the same diameter will require different burst charges depending on space constraints.

The purpose of this article is to provide a better understanding of various types of burst charges and the parameters that dictate their usage. Once you understand the fundamentals and develop a feel for the strength of the most common burst charges, you will find that the trial and error required to produce a new shell will be greatly reduced.

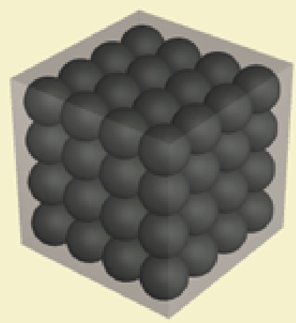
The major burst charge parameters explored here include the grain size, the ignitability of the grains, the rate of flame propagation between the grains and the burn rate of the most common burst charges.



Grain Size: 1"
Surface Area: 3.14 sq. in.



Grain Size: 1/2"
Surface Area: 6.28 sq. in.



Grain Size: 1/4"
Surface Area: 12.57 sq. in.

Grain Size:
One of the most useful methods of controlling the burn rate of a burst charge is to control the exposed surface area. This allows us to dial in the strength of a given charge without altering the formula itself. The basic idea is to process the burst charge into grains of a specific size. The grains are shaped such that there are air gaps between them, thus allowing the hot gasses to rapidly propagate between all particles almost instantly. The exposed surface area of the powder is effectively the sum total of the surface areas for each grain.

The diagram above illustrates the relationship between grain size and surface area. A spherical grain shape has been used to simplify the surface area calculation. If we had one single grain contained in a one cubic inch box, the surface area would be 3.14 square inches. If the grain size were cut in half, then eight grains would fit in the same space, giving a combined surface area of 6.28 square inches. If the grain size was again reduced by half, a total of 64 grains would fit in the same space and yield a surface area of 12.57 cubic inches.

It can be seen above that each time the grain size is cut in half, the exposed surface area of the charge is doubled. While the burn rate of the powder does increase considerably as the grain size is reduced, the burn rate increase does not correspond in a direct ratio with the increase in surface area. As the grains get smaller, the gaps between them also get smaller as well, thus creating more resistance for the hot gases trying to work their way between them.

This delayed propagation means that the entire surface area will not ignite simultaneously. Thus there is a point of diminishing returns after which the burn rate will not increase anymore as the grain size is decreased. In fact, the burn rate trend will actually reverse itself beyond a certain point. For this reason grains smaller than 50 mesh are not generally used in fireworks, and even that size is only used in small quantities so that the propagation rate is not an issue.

Grain size is an important tool for adjusting break charge strength. As shells get larger and the space to be filled by the break charge increases, the strength of the break charge must be decreased accordingly. For larger shells above 8" diameter, even downshifting to the weakest break charge (black powder) is not enough. You must slow the burn rate even further by increasing the grains size as the size of the shell increases.

Ignitability:
For lack of a better word, I am using this term to refer to the amount of time it takes a powder grain to ignite. While the round grains illustrated above made the surface area math easy to calculate, they do not make a very optimal grain shape for burst charges. This is because smooth, round surfaces do not take fire as easily as jagged grains with sharp edges. The reason for this is that heat being applied to a point on the surface of a sphere is more readily absorbed into the surrounding area, as seen in Figure 1. Because heat is being drawn away from the ignition area, it will take longer for the grain to reach its ignition point. This phenomenon is an even larger issue with round stars, since they sit at the outer edge of the flame front and have the shortest amount of time to take fire before the shell bursts.

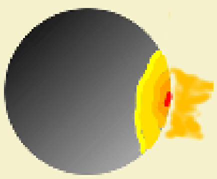


Figure 1: Heat absorption around heated spot on a sphere.

Jagged surfaces and sharp corners like the one shown in Figure 2 will take fire quite rapidly, since the heat does not have any immediate surroundings to bleed into. The less mass there is to absorb heat, the faster that mass will heat up and ignite. This is why you can hold a blowtorch up to a sheet of plywood for several seconds without burning it, while the same amount of heat applied to a tooth pick would burn it up instantly. The sharp edges on cut stars and pumped stars also explains why they ignite better than round stars (although spiking the prime layer on your round stars as recommended by this site will get around this problem).

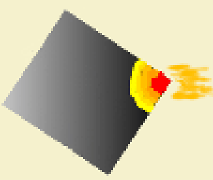


Figure 2: Heat absorption around heated corner of a cube.

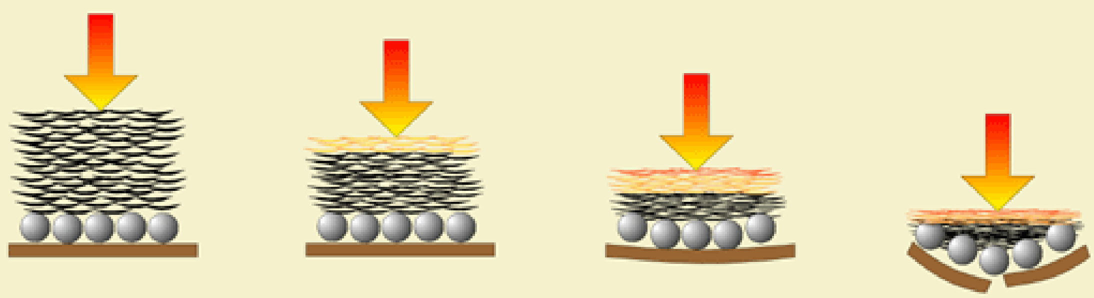
Ignitability is not usually an issue with burst charges, since they are typically rolled onto irregular shaped cores such as rice hulls or cotton seeds. There are occasions when a burst charge is rolled directly onto round stars in a shell, in which case the slower ignition must be accounted for.

More...

Burst Charges...

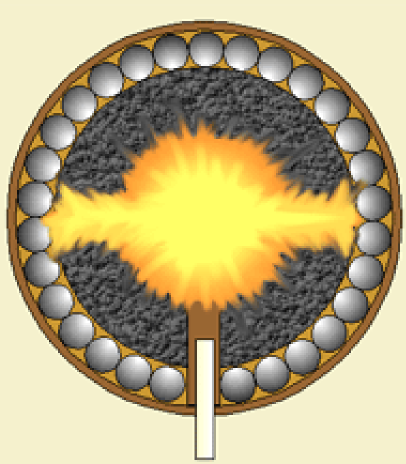
Flame Propagation:
Flame propagation refers to the movement of hot gasses between the grains in a burst charge. An effective burst charge will contain plenty of air gaps so the initial ignition point can spread rapidly throughout the entire shell before it bursts. There are three main aspects of the powder grain that will control flame propagation: size, shape and compressibility.

The effects of grain size have already been mentioned, with smaller grains leaving smaller passages that require higher pressures and longer propagation times than the big airy gaps left by larger grains.



The shape of a grain can also effect flame propagation. The worst grain shape would be a flat one, such as a burst charge rolled onto flakes of paper or oatmeal. A flat grain would tend to stack in a dense configuration that would hinder flame propagation, creating a "fire-block."

The only thing worse than a flat grain would be a compressible flat grain, which is why I think the type of rice hulls used by many hobbyists are not the best choice in many cases. A flakey, compressible charge like this can be made to work in smaller shells where the flame doesn't have that far to propagate, or it can be made to work if the burst coating is applied so thick that the charge is no longer compressible. Rice hulls also work good for cases where the space available for the burst charge is very limited, such as in a double petal type shell. However, using this type of charge in a shell where the flame has very far to travel, such as in a multi-break canister, peony larger than 5" or ring & bowtie shell of any size is just asking for trouble.



The sequence above shows what can (and does) happen with rice hull charges that are used to fill large volumes within a shell. Following the central ignition, the hot gases begin to push outward in all directions. As the gases push their way into the rice hulls, the hulls begin to compress and further restrict the available passages for the gas to travel. The more the passages get restricted, the more the pressure becomes one-sided. This eventually compresses the hulls to a point where they are just end-burning from the center outward, and the shell will often break before the fire ever gets to the stars. A rigid grain with a rounded or granular shape to allow plenty of air gaps does not suffer from this problem.

Figure 3 shows the flame propagation in a shell containing a burst charge that is too dense to allow good flame propagation. The gasses will quickly spread out along the central gap where the two shell halves meet, igniting the stars that are at the perimeter of the seam and working outwards from there. The central flame front may never reach the stars at the ends of the shell

Figure 3: Flame front of a ball shell.

before it bursts. If you ever had a shell break that seemed pretty sparse but still somewhat round, or a ring and bowtie shell where the bowtie was blown blind but the ring lit, this is the likely cause.

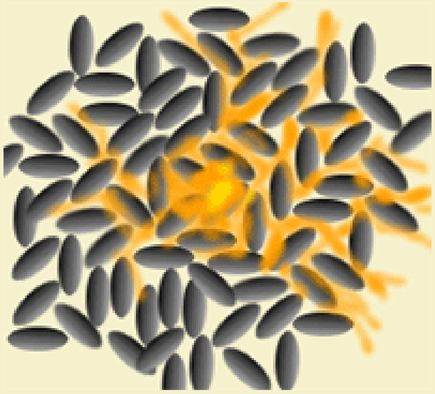


Figure 4: Flame propagation through puffed rice break charge.

Figure 4 shows a simulated flame propagation between the grains of coated puffed rice cereal, my favorite burst charge core for 6" and 8" shells. This charge is very rigid, leaves lots of air gaps and is very light weight (thus saving you lift powder). This charge is also much closer in appearance to the rice hull charges used by the Chinese in commercial shells of the same size range.

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Burst Charges...

Burst Charge Types:
As if there were not enough variables to keep track of at this point, the following information outlines five of the most common break charges in order from strongest to weakest. The rule of thumb is to use stronger charges for smaller shells and weaker charges as the shell grows in size. If your shell bursts with uneven symmetery, then the burst charge needs to be strengthened by making the grains smaller, using more charge or by using a stronger charge (making the casing stronger also helps fix the problem). If the shell breaks too hard or stars are blown blind, then the burst charge needs to be cut back by using larger grains, using less charge or using a weaker mix.

Flash:
Flash is the strongest of all burst charges and must be used in moderation. There are various flash formulas used for breaking shells, each designed for a specific break system. Straight 7-3 Flash is the strongest option that will produce the hardest breaks. Variations on the basic flash formula often add other components such as sulfur and antimony, sometimes called "dirty flash" formulas. These burn less fiercely than flash and have less problems with blowing stars blind. The Ofca Flash attempts to improve star ignition by driving droplets of molten antimony into the stars, and is considerably slower burning than other flash formulas.

Preperation
Formulas: Standard Flash, Bleser Flash, Ofca Flash

Extreme caution should be used when mixing flash formulas, especially those containing dark aluminum such as German or Indian black head. Fine aluminum and potassium perchlorate are a friction sensitive combination, thus screening or any kind of grinding action should be strictly avoided. Flash formulas containing American dark aluminum (809) are not as sensitive due to the stearine coating on the aluminum, and they are less likely to over break the shell as well. All flash formulas are also sensitive to static electricity, so care must be taken to avoid mixing in dry climates and to ground yourself before working. Individual components should be pushed through a screen separately and then diapered together using a sheet of paper to rock them back and forth until adequately mixed.

Usage
Flash can be coated onto rice hulls for use in smaller shells under 3", but it is most commonly employed using a flash bag to locate a small amount at the center of the shell. A flash bag can be a paper or plastic bag containing a small amount of flash, which is tied off to the time fuse. A simpler method is to place the flash on a small sheet of tissue paper, then pull the corners together and twist them to form a little bag that is placed at the center of the shell. For smaller shells the flash bag method allows more stars to be used, but this becomes a costly feature as the shell size increases. In shells between 4" and 6" flash is most often used as a booster in addition to another type of burst charge that fills the empty space. The use of flash is not recommended for shells larger than 6". Flash breaking shells has the disadvantage of creating a very bright flash that can cause spots in the eyes of the viewer, and is not recommended for any delicate streamer effects.

Whistle:
Whistle mix is second in line for burst strength after flash, and has the advantage of not creating the bright flash that flash does.

Preperation
Formula: Whistle Burst

Unlike flash, the components of whistle mix can be safely screened together. Ball milling should be strictly avoided though. The sensitivity to static electricity is the same as for flash and the same precautions must be taken to avoid it. Whistle mix made from sodium salicylate will provide a stronger burst charge than that made from sodium or potassium benzoate. The formula is the same regardless of which fuel you use: 70% potassium perchlorate mixed with 30% potassium benzoate, sodium benzoate or sodium salicylate.

Usage

Whistle mix is used in the same way that the flash burst charges are used. It can be coated onto rice hulls for small shells, used in a central "flash bag" tied to the time fuse, or loosely added as a booster to another burst charge type. Because whistle is safer to mix and store, and does not produce the distracting white flash, it is a more desirable alternative to flash breaking shells.

H3:

H3 is a powerful burst charge originally published in Shimizu's Fireworks- Art, Science and Technique. It generates an explosive force about 2.4 times stronger than black powder. Unlike KP, the burn rate of H3 is not dependent on pressure and it burns quite rapidly in open air.

Preperation

Formula: H3 Burst

The simple formula consists of 75% potassium chlorate and 25% charcoal, with the addition of 2% glutinous rice starch or dextrin to help it adhere to whatever cores it is to be rolled on. The components can be safely screened together, but ball milling should be strictly avoided. H3 is most commonly rolled onto rice hulls in a ratio of 4:1, or it can also be riced into granular form using the same method as for producing rough powder. Using the granular form is ideal for shells 2" in diameter or less. When using the granular form it is important to maintain grain size consistency, as the strength of the charge will be highly dependant on grain size and failure to control this variable will give you inconsistent results in your shells.

Usage

This charge is most often used in smaller shells that require a more energetic burst charge to function. It can be used in 2.5" and 3" plastic shells without the need for additional flash or whistle mix boosting. It also makes a great burst charge for 5" spider shell canisters, which allows the stars to be blown out hard in straight lines without the retina spotting white flash you get from using flash bags to achieve the same effect.

Some builders are deterred from using this charge due to the presence of chlorates. However, as Shimizu notes, this charge is "unexpectedly insensitive to shock and friction." Repeated drop tests showed it to be only slightly more sensitive than black powder, but less sensitive than KP! However, if it comes in contact with sulfur containing compounds, it becomes highly sensitive. A shell containing H3 that fails to burst and falls back to the ground will often detonate on impact if there is no barrier between the H3 and meal coated stars in contact with it. Thus it is wise to keep the H3 from coming into contact with any meal coated stars using tissue paper barriers.

KP:

The KP burst charge was developed in 1955 as an alternative to the chlorate containing H3 charge. While it is not strong enough to replace H3 in shells smaller than 4", it makes a great burst charge for shells in the 4" to 6" range. The advantage over H3 is that there are no sensitivity issues when coming into contact with meal primed stars.

While the explosive force generated by an equivalent amount of H3 and KP are about equal, H3 burns three times faster than KP in open air. Even black powder burns two times faster than KP in open air. Igniting a small sample of KP on the ground would lead one to believe that it burns too slowly for use as a good burst charge. How is it then that KP performs so well?

The distinctive characteristic of KP is that its burning rate substantially increases as the surrounding pressure is increased. Thus KP burns much faster inside the shell as the pressure builds up than it does in open air. Because of this characteristic, the strength of a given charge can actually be adjusted by increasing or decreasing the thickness of the shell wall. It is in fact possible to build a 3" shell using KP that breaks with the same force as one using H3, it's just that the KP shell would require a thicker wall to the point that the extra pasting would not be worth the trouble.

Preperation

Formula: KP

The formula for KP given by Shimizu is 70% potassium perchlorate, 18% charcoal and 12% sulfur with an additional 2% glutinous rice starch or 5% dextrin added to help the material stick to whatever core it is rolled onto. Using the same 75-15-10 formula as for black powder also works well, making a simple substitution for potassium nitrate using the perchlorate. All compounds can be safely screened together and should be mixed well. I prefer to ball mill the sulfur and charcoal components together, then screen in the perchlorate. The full mix should not be ball milled however, as KP is more sensitive to friction than black powder.

Usage

KP is most often rolled onto rice hulls or similar sized cores. It is ideal for usage in shells in the 4" to 6" range, as it is too strong for shells larger than 6". KP is also an effective burst charge for rolling directly on the stars, as its fast burn rate under pressure makes up for the exposed surface area lost when rolling onto large cores such as the stars themselves.

BP (black powder):

This is the oldest, cheapest, safest and the weakest burst charge. BP is the charge of choice when large volumes of burst charge are required, such as 6" ring shells, 8" single petals and all shells 10" and larger. BP has only half the explosive force of KP or H3, thus a lot more of it is required to break a given size shell.

Preperation

Formula: Black Powder

Black powder requires much more work to produce compared with the other break charges listed here. The type of charcoal used plays a major role in the strength of the powder, and all components must be intimately mixed using a ball mill or similar grinding method. For use in burst charges, the standard 75-15-10 formula is used with the addition of 5% dextrin for binding purposes. It is easiest to ball mill the dextrin along with the other three components rather than trying to screen it in with milled meal powder later. Full details for producing high quality BP can be found here.

Usage

For mid sized shells BP is most commonly coated onto rice hulls or similar cores. I find 4:1 BP/puffed rice the best choice for 6" ring shells or 8" single petal shells. For larger shells, cotton seeds are the core of choice due to their larger size, low cost and ease of preparation. The fuzzy seeds allow the powder to strongly adhere to the surface, and they dry easily as well. For more details on coating cotton seeds, click here.

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