

## Section 2: Basic Aerial Shell Components and Functioning

### Firework aerial shell shapes and sizes

- a. Spherical
- b. Cylindrical

Aerial shells are 2 basic styles of aerial shell construction:

- **Spherical Aerial Shells** (often referred to as Japanese or oriental-style shells). Spherical shells typically produce star patterns that are spherically symmetric.
- **Cylindrical Aerial Shells** (often referred to as canister, Italian or American-style shells). Cylindrical shells typically produce less symmetric star patterns.



*Fig. 2.02: Aerial shells comparison. Photo: courtesy of FireworkFX.com. Fig. 2.03: Various ball (round) shells with leaders, including finale chain (right). Photo: IPM Universal*

Examples (photo above) of various weights of shells of the same 3-inch caliber. Italian shell weight of (1012g), Spanish (660g) and Chinese (312g).

Aerial shells range in size from less than 2 inches (50 mm) to more than 12 inches (300mm). However, most shells used in displays are between 2.5 and 6 inches (65 and 150mm).

Aerial shells are measured in terms of the internal diameter of the tube (fireworks mortar) from which they are designed to be fired.

Because of the need for clearance between the aerial shell and mortar, actual shell diameters are less than their nominally stated size. For example, most 3-inch (75mm) shells are about 2.7 inches (66mm) in diameter.

Aerial shells must be constructed to fit properly in the mortar such that they will be propelled to the proper height before functioning.

## Types of Aerial Shells



**Fig. 2.04-2.05:** Various sizes ranging from 2-inch to 12-inch spherical Chinese aerial shells (above) and cylindrical shells from size 2.5-inch to 6-inch (below). Photos: Liuyang Candour Fireworks Co., Ltd.

**Spherical Aerial Shells** – are commonly made in China and Japan.



**Cylindrical Aerial Shells** – are somewhat more commonly made in Europe and the United States.



**Fig 2.06:** Examples of cylindrical shells and cut-away. Photo: by dagabu from AmateurPyro.com forum.  
**Fig. 2.07:** Here is a typical Maltese-style Italian (200mm) cylinder shell. Photo: Martarello Group, Italy

## Basic Cylindrical Aerial Shell Components

Illustration of the basic components of a spherical ball (cylindrical) aerial shell in its mortar.

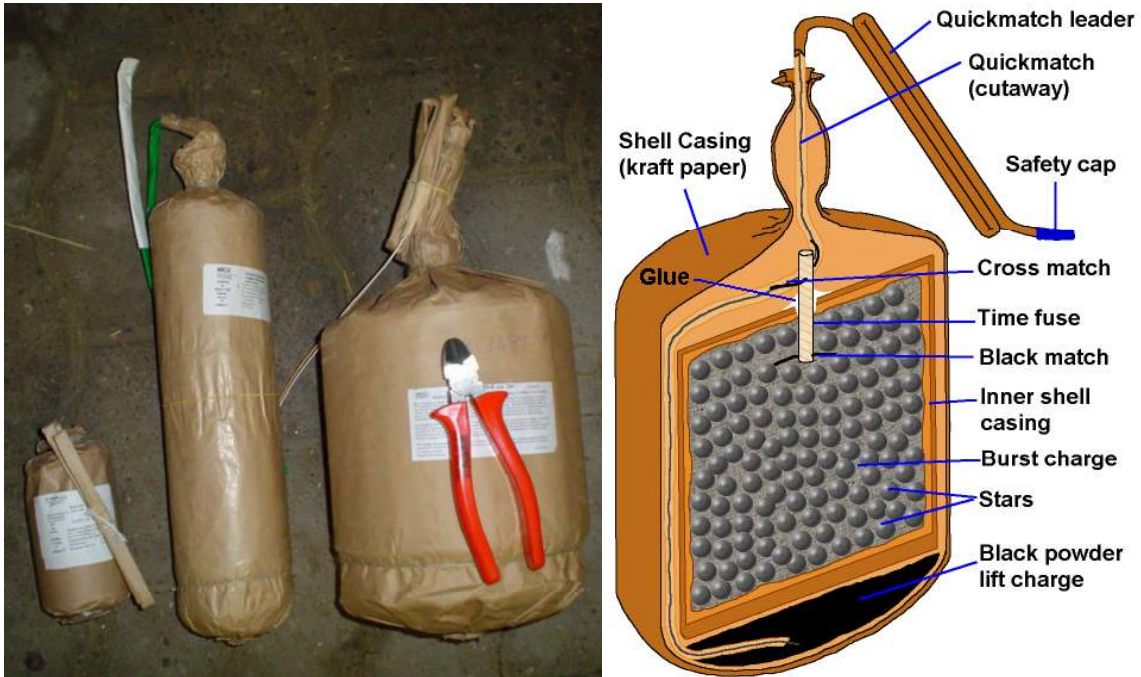


Fig. 2.08: Variation of cylindrical shell. Photo: 1PYRO8 Media. Fig. 2.09: Parts of cylindrical display shell. Illustration: courtesy of Pyro Universe

### Manner of Aerial Shell Functioning (Manual Firing)

An aerial shell is a ballistic projectile fired from a tube (a mortar). The sequence of events is:

- Safety cap, which protects the exposed black match, is removed (not shown). The black match or other delay element is ignited and provides 2 to 6 seconds of delay.
- When burning reaches the start of the quick match portion of the shell leader, it burns quickly, in about 0.3 second.
- When the burning shell leader fuse reaches the Black Powder lift charge, it is ignited.
- The burning lift charge produces combustion gases that are partially confined within the mortar. The burning gas pressure that is produced propels the shell upward and ignites the shell's time fuse.
- The aerial shell, having exited the mortar, travels skyward (coasting upward) while the time fuse continues to burn.
- Eventually, the time fuse burns through to ignite the burst charge and stars in the shell. This burning produces an increasingly high pressure inside the shell. When the internal pressure exceeds the strength of the shell casing, it bursts to expel the burning stars in a display of light effects.



### Firework Mortars

Although not physically part of an aerial shell, the firework mortar is essential to properly fire the shell into the air.



Fig. 2.11: Wooden racks holding 2.5-inch and 3-inch HDPE mortar tubes for aerial shells. Photo: IPM

The fit between the aerial shell and mortar determines how much of the burning lift gas will escape. Thus, a proper fit is necessary for the shell to be propelled to a safe height.

The fit of an aerial shell in a mortar should be “close but freely sliding.”

Accordingly, each different size aerial shell requires a different size firework mortar.

### Basic Aerial Shell Components

Illustrations of the basic components of a spherical aerial shell.

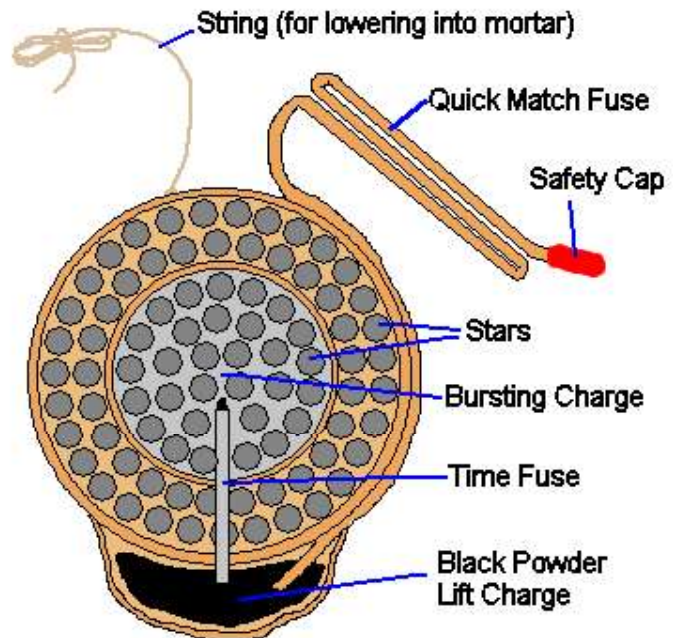
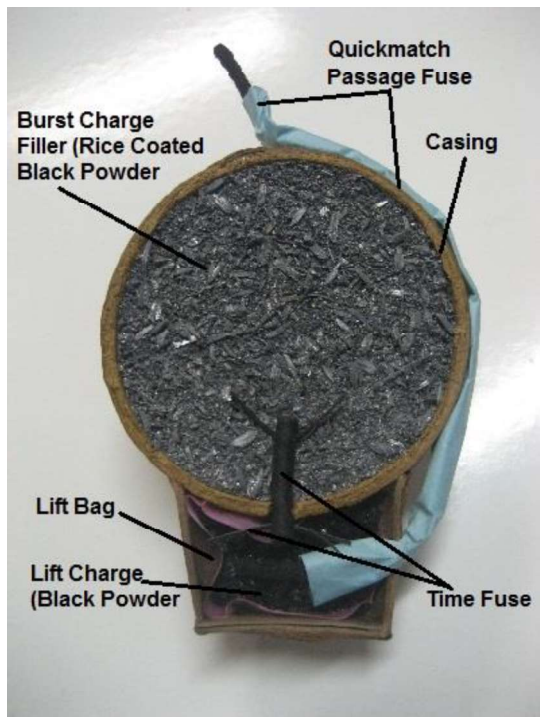


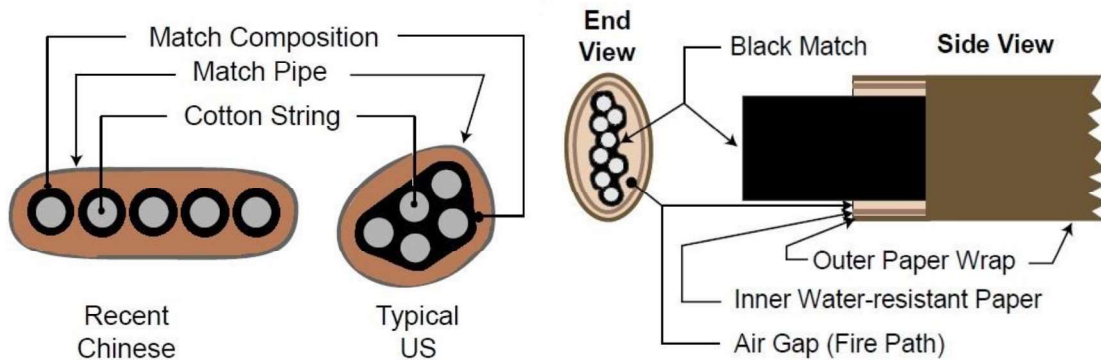
Fig. 2.12: Inert of 4-inch shell components. Photo: Explow.com. Fig. 2.13: Diagram of spherical display shell. Illustration: from Pyro Universe

### Shell leaders (fuse)

- a. Black match
- b. Quick match

### Black Match and Quick Match

**Black match** is made by coating slurry of **Black Powder** on cotton strings, to produce a fuse about 1/8" x 1/4" (3 x 6mm) in cross section. Black match burns at a rate of about 1 inch/second (25mm/s).

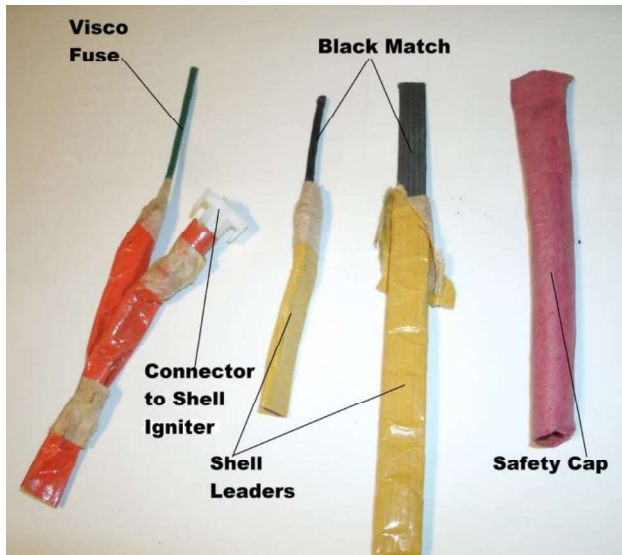


**Fig. 2.14: Illustrations featuring configurations of two types of quick match and black match. Fig. 2.15: Illustration: courtesy of Journal of Pyrotechnics**

**Quick match** is made by simply wrapping black match with a loose paper covering. Quick match burns at a rate of about 15 feet/second (5 m/s); approximately 200 times faster than black match.

### Black Match, Quick Match and Shell Leaders

Examples of two thicknesses of black match and one example of quick match.



**Fig. 2.16: Visco green fuse leader (left) and thin black match leader (right). Fig. 2.17: Shell leader with red safety cap attached to 6-inch ball shell. Photos: IPM Universal**

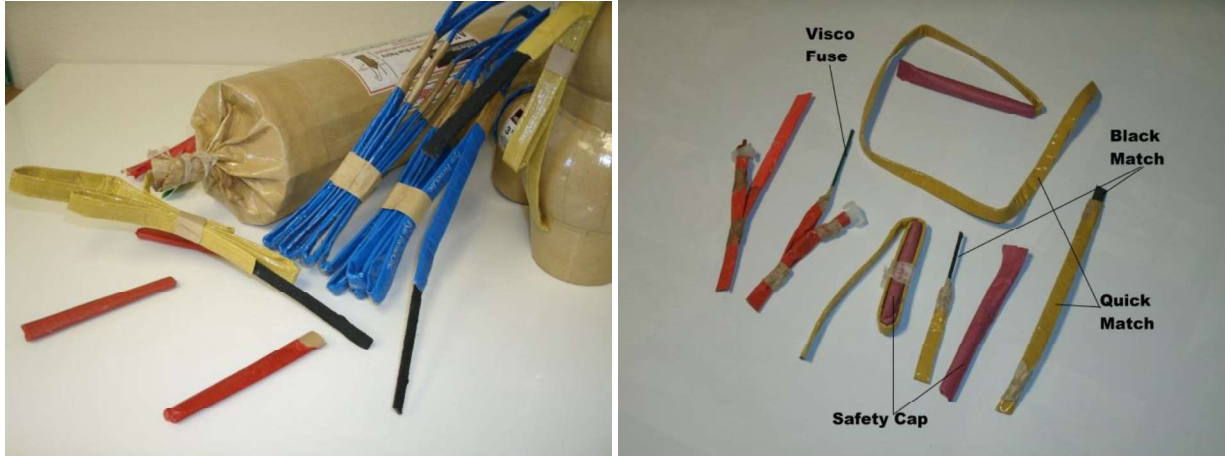


Fig. 2.18-2.19: Various examples of shell leaders and safety caps (red). Photos: IPM Universal



Fig. 2.20: Black match (piped). Photo: IPM Universal

### Match Burning Explained

The rapid burning of quick match can be explained using the analogy of a candle flame. Black match burns much like an unobstructed candle flame. Quick match burns much faster because its flame spreads along the paper wrap (like an obstructed candle flame) progressively igniting more and more powder.

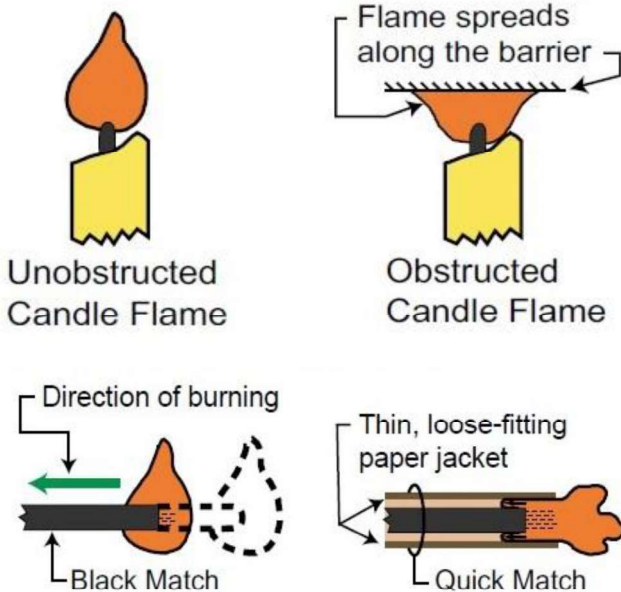


Fig. 2.21: Unobstructed Candle Flame. *Journal of Pyrotechnics*

#### “Black Match”

Black match exhibits essentially “parallel” burning at about 1 inch per second (25mm/s) except for sparks jumping ahead.




#### “Quick Match”

Flame spreads along the inside of the paper jacket, rapidly igniting more and more black match. Quick match burns “propagatively” at about 15 feet/second (5m/s), about 200 times faster than black match.

### Fireworks Lift Charge (Propelling Charge)

The **propellant** for aerial shells is essentially always granular **Black Powder (gun powder)** made of an intimate mixture of 75% potassium nitrate, 15% charcoal and 10% sulfur. This is often referred to as “**lift powder**” or simply as “**lift**”.

Generally, finer granulations are used for smaller fireworks aerial shells and coarser granulations are used for larger aerial shells. Also, spherical shells tend to use finer granulations compared to the same size cylindrical shells.

Grade	Appearance	Typical use
2FA		Cylindrical shells 3-inch (75mm) and larger
4FA		Cylindrical < 3" (75mm) Spherical >3" (75mm)
5FA		Spherical shells smaller than 3-inches (75mm)

*Table 2.1: Variation of grain sizes of black powder. Photos: courtesy of Pyro Guide*

Some civilian Black Powder granulations commonly used in the U.S. are listed (on the next page) with their range of particle size.

Some Black Powder granulations commonly used in the U.S. are:

Grade	US Mesh	Smaller Than		US Mesh	Larger Than	
		inch	mm		inch	mm
2FA	4	0.19	4.8	12	0.066	1.7
3FA	10	0.079	2.0	16	0.047	1.2
4FA	12	0.066	1.7	20	0.033	0.85
5FA	20	0.033	0.85	50	0.012	0.30
7FA	40	0.016	0.42	100	0.006	0.15
Meal D	40	0.016	0.42	No Limit on fineness No Limit on fineness		
Meal XF	140	0.004	0.11			
Cannon	6	0.13	3.4	12	0.066	1.7
Fg	12	0.066	1.7	16	0.047	1.2
2Fg	16	0.047	1.2	30	0.023	0.60
3Fg	20	0.033	0.85	50	0.012	0.30
4Fg	40	0.016	0.42	100	0.006	0.15

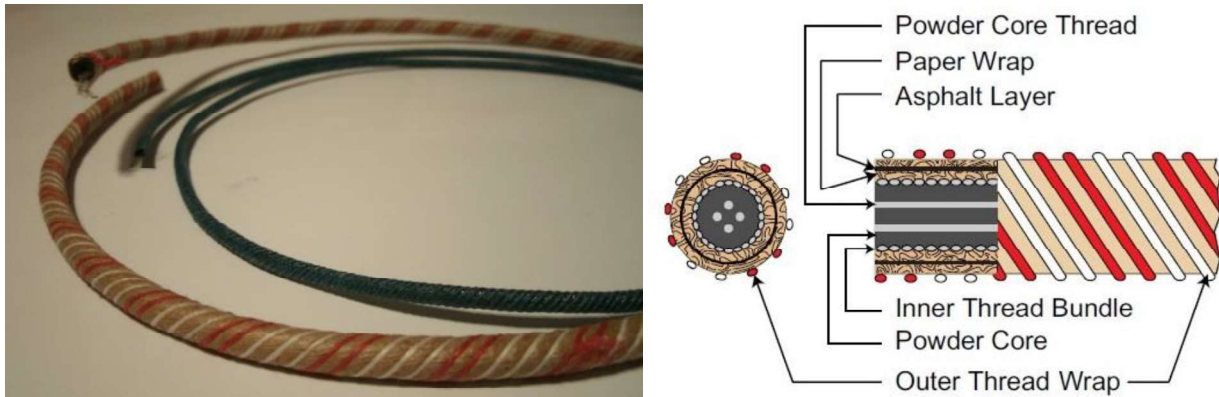
**Table 2.2: Grade powders 2fA, Meal D, Meal XF, Cannon Fg, 4Fg. Journal of Pyrotechnics**

At least 85% of the powder will fall between the two particle size limits.

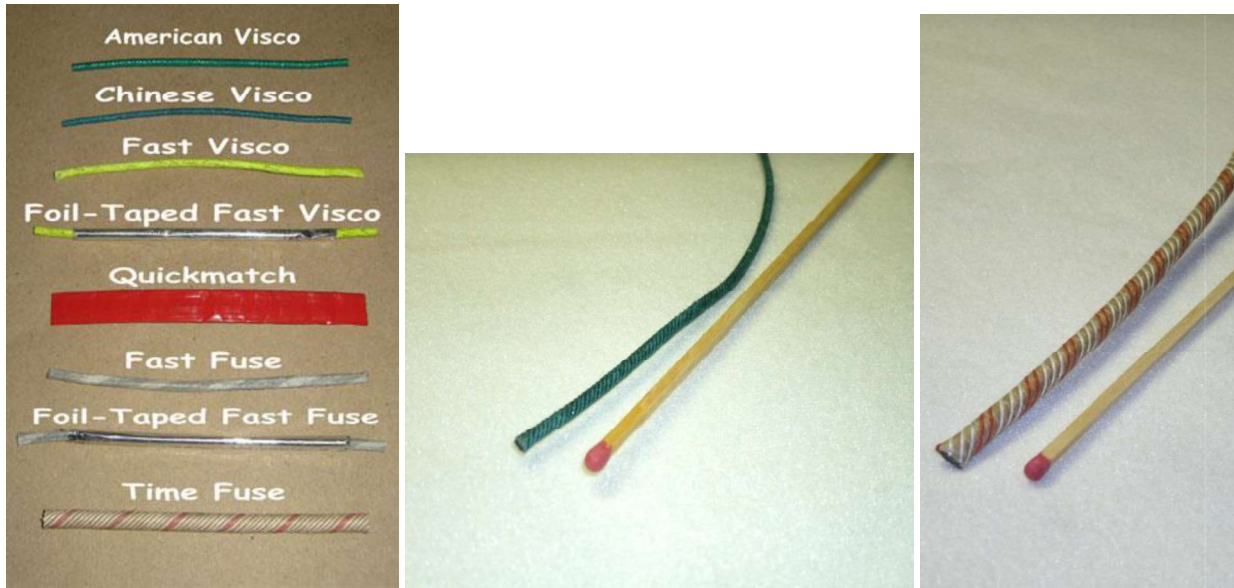
Black Powder is often coated with graphite, in part for improved moisture resistance, but mostly to make it free flowing and less dusty.

### Fireworks time fuse (delay fuse) and priming

Fireworks **time fuse** is an internally burning fuse, generally about ¼ inch (6mm) in diameter. It has an ample powder core and burns about 1/3 inch/sec (8mm/s). Time fuse is somewhat water resistant.



**Fig. 2.22: Photos showing green Visco fuse and Chinese time fuse (left). Photo: IPM Universal. Fig. 2.23: Illustration of the general construction of Visco fuses. Illustration: Journal of Pyrotechnics**

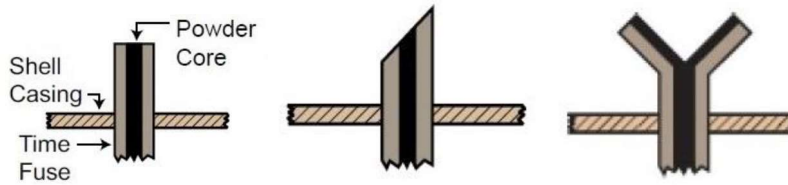


**Fig. 2.24-2.26: Examples of various types of fireworks time fuses. 30mm Visco and Chinese time fuse.**  
 Photos: Skylighter (left) and IPM Universal (middle and right)

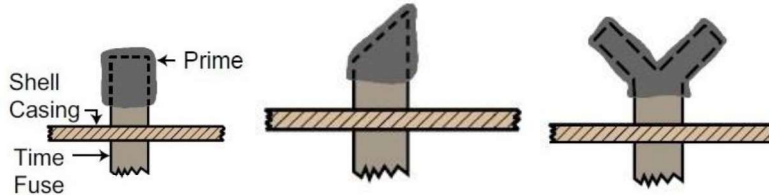
### Time Fuse Ignition

To increase the probability of time fuse ignition as an aerial shell fires from its mortar, some method of “priming” is generally used. The outer end of the cut fuse (as in 1) may be coated with prime (as in 2), or a piece of black match may be inserted into a hole punched through the time fuse (as in 3).

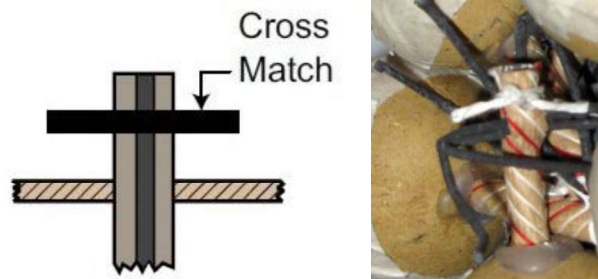
#### 1 No Treatment



#### 2 Prime Application to 1



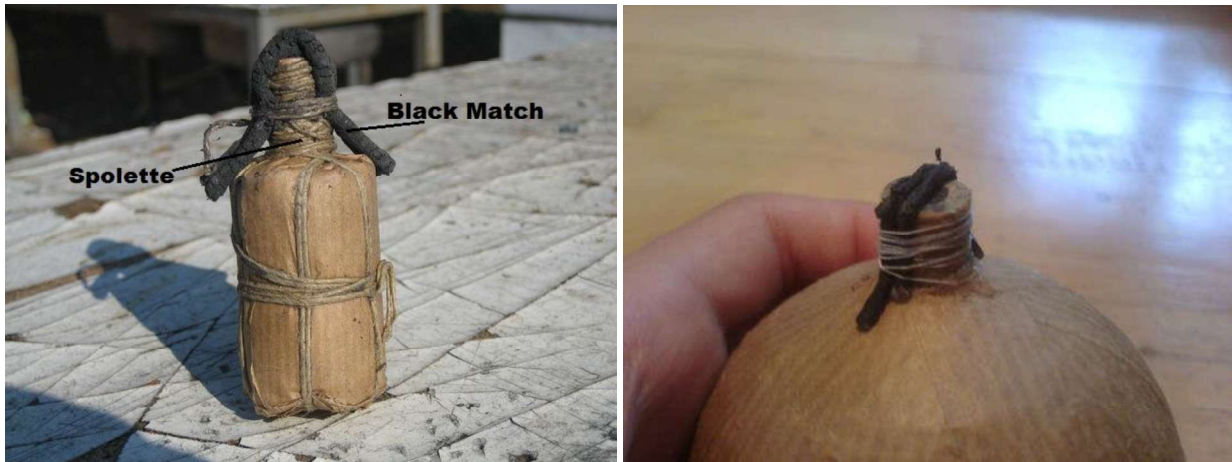
#### 3 Cross Matching



**Fig. 2.27: Various kinds of time fuse ignition used in shells. Illustrations: Journal of Pyrotechnics**

## Priming Techniques

In “cross matching”, a small hole is punched through the time fuse and a piece of black match is inserted.



*Fig. 2.28: Colpo DiScala Italian components of Cylinder Shell Adelfia Bariltaly. Photo: Pyromartin Feuerwerkforum.de. Fig. 2.29: Cross matching on 3-inch shell. Photo: Instructables.com*

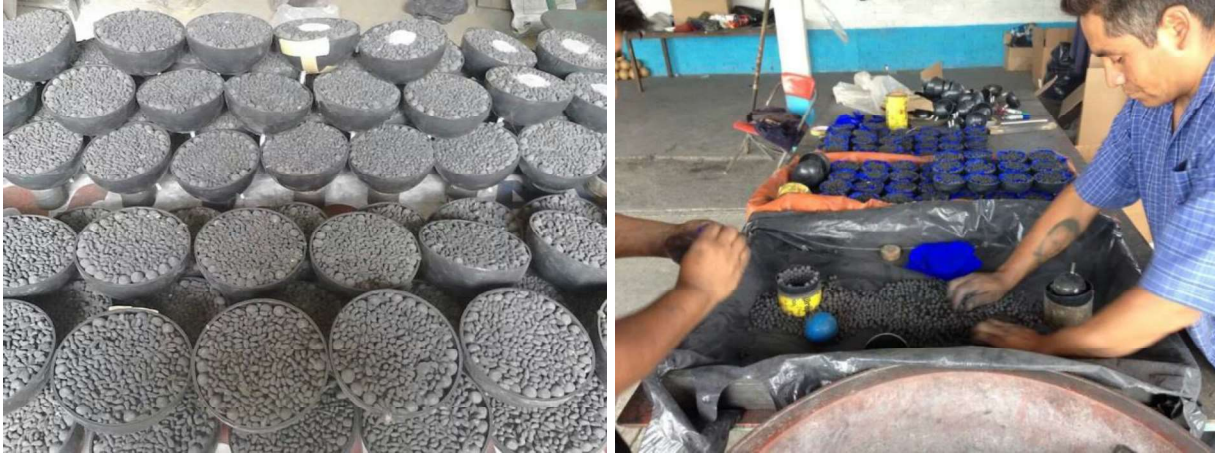
An example of a time fuse that has been coated with prime composition (fine Black Powder mixed with a binder) that was then dipped into granulated Black Powder to further increase the likelihood of ignition.



*Fig. 2.30-2.31: Cross-Match. Photos: Harry Gilliam at Skylighter.com. Cross fused shell, Liuyang China*

## Fireworks Stars (pellets of pyrotechnic composition)

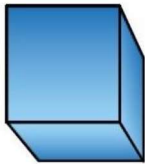
Fireworks stars are pellets of pyrotechnic composition that burn to produce the visual display in the sky. Depending on the method of manufacture, the pellets may be spherical, cylindrical or cubic. They can produce colored light, a trail of sparks, or both.



*Fig. 2.32-2.33: To the right are examples of stars being loaded into aerial shells. Photo credits: Fireworks FX, Inc. and Mexico fireworks factory*

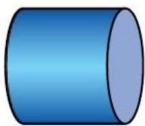
The size and chemical composition of stars determines how long the stars will burn.

### Star Shapes



Fireworks stars are made in a variety of shapes.

**Cut stars** are manually produced using a technique much like dicing in cooking. Cut stars are most often approximately cubic in shape.



**Pressed stars** may be produced manually or mechanically where the star composition is compacted into a cylindrical form to produce a cylindrically shaped star.

**Rolled stars** are made in a rotating drum in which successive layers of star composition are built up (something like the layers of an onion). Rolled stars are nearly spherical in shape.



Stars are almost always coated with a Black Powder prime to help insure their ignition.

### Shell inserts (small pyrotechnic components)

In addition to (or in place of) stars, aerial shells may contain shell inserts.

**Shell inserts** are individually small firework devices such as:

- Small **salutes** (also called shots, reports, crackers or Siatene).
- Small **aerial shells**.
- **Whistles**.
- **Saxons** (small spinning fireworks producing a trail of sparks).
- **Hummers** (small spinning fireworks producing a humming sound and possibly a trail of sparks).

Aerial shells containing inserts are commonly called “component shells” and the inserts may be called “components”.

### Fireworks Shell burst charge (break charge)

The explosive charge that bursts an aerial shell is generally referred to as the “**burst charge**” or “**break charge**”. Most often, it is made by coating a pyrotechnic composition on rice hulls (then called “rice hull powder”). The coating can simply be handmade Black Powder but may be a more energetic composition made using potassium chlorate or potassium perchlorate and charcoal. In cylindrical aerial shells, the break charge can be commercial or handmade granular Black Powder.

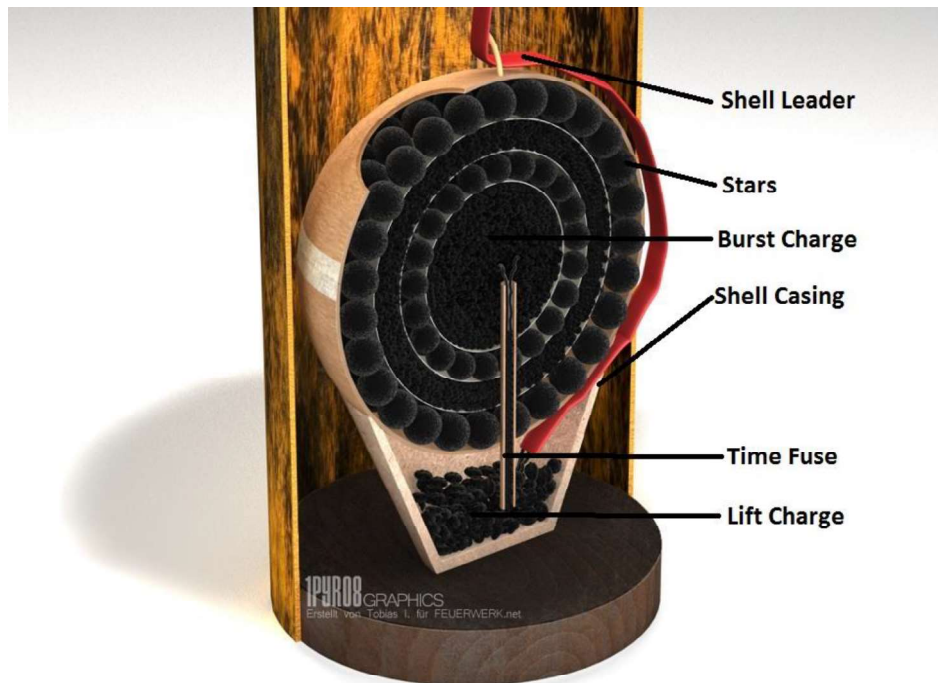


*Fig. 2.35-2.36: Example of rice hull powder. Black Powder coated rice hulls. Photo: PyroFlo, Feuerwerk.net*

The break charge may be placed in the center of a pattern of stars or may simply be mixed in randomly with the stars.

### Spherical (Ball) Aerial Shell

This is a cut-away model of a spherical aerial shell. The model demonstrates the typical appearance and placement of the components of a spherical aerial shell.



*Fig. 2.37: Diagram of spherical aerial shell. Illustration: 1Pyro8 Graphics, Feuerwerk.net*

## Aerial Shell Label Examples

The following illustrates typical shell labels. A typical U.S. shell labels with detailed information.



Fig. 2.38: 5-inch shell labels. Photo: UKFR.com. Salute shell labels. Fig. 2.39: Photos: Rick Levin & Associates Auctions

## Consumer Fireworks Aerial Shells

**Consumer fireworks** aerial shells are occasionally used in small public displays. These come in two varieties.

One type, **reloadable**, is just a smaller version of display fireworks aerial shells. The shell, complete with leader fuse and lift charge, is loaded into a reusable mortar before firing.

The other type, **single shot**, comes with the shell already loaded in its mortar. Usually the lift charge is loose in the mortar below the shell and is ignited with a slow burning fuse through the side wall of the mortar.



Fig. 2.40: Reloadable "pro" artillery shells by Big Fireworks. Fig. 2.41: Storm artillery shells by Klasek Trading, s.r.o., courtesy PMCOstrava.cz; Single shot mortars from Global-Pyro.com (right)

## Common Aerial Shell Burst Patterns and Associated Terms



**Chrysanthemum** – A common spherical “floral” pattern in which the stars leave a visible trail.

**Peony** – A spherical pattern in which the stars leave no visible trail (giving the appearance of points of light radiating outwards from a central burst). Two or three color changing peony effects are common in the larger sizes.

**Willow** – Long burning golden stars cascading downwards in a non-spherical ‘weeping willow’ pattern. The effect may reach the ground. Often

undesirable effect when fire danger is extremely high.



**Brocade** – Similar to a **Kamuro** effect, but with shorter burning stars.

**Palm** – Large, bright gold or silver stars that permeate outwards – giving the appearance of a palm tree. An **Octopus** shell is similar to a palm but has, specifically, eight thick tendrils (arms).



**Crossette** (“**Splitting Comets**”) – Stars which split into several components, producing a ‘criss-cross’ effect in the sky.



**Strobe** – An effect that ‘pulsates’ in the night sky. Similar to glitter but at a lower frequency – giving the appearance of numerous cases, long duration strobes may also reach ground



flash bulbs. In some level

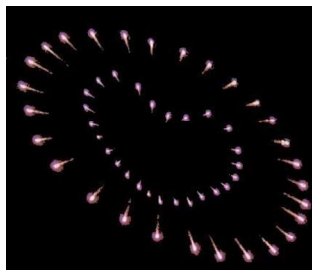
**Diadem** – Usually style shell. Example:

refers to a ‘final effect’ at the end of a willow or Kamuro Gold Willow to Red Diadem.

**Pistil** – A central effect that is often incorporated into peony or chrysanthemum shells (not exclusively). Example: Red Peony with Blue Pistil.

**Falling Leaves** – A gentle effect where the ‘stars’ drift downwards in a small cluster. The ‘leaves’ are often slow burning fuse as opposed to rapidly burning pressed composition.

**Horsetail (Waterfall)** – An willow effect (usually gold or silver) in which the stars fall in a cluster – giving the appearance of a horses tail. This is achieved by ensuring that the shell has a ‘soft break’ so that stars are not propelled vigorously from a central point.



**Pattern Shells** (i.e. Heart, Saturn Ring, Snail, Star, Cube, Smiley Face, Butterfly) – Shells designed to break so that the stars emerge in a well-defined geometrical pattern. The effect is not always seen clearly as the burst may not eject the stars at the correct viewing angle.

**Salute (Maroon)** – A shell designed, in its simplest form, to give a single report. Salutes made with flash powder are more vibrant than those made with traditional black powder but also more volatile.

The range of shells now available is huge and the combinations of effects are almost endless. The above list of terms is by no means exhaustive.