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Another Example of Explosively Malfunctioning Comets[1]

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This article reports on another batch of comets, imported from China, that tend to malfunction by exploding violently within their mortars as they are being fired. In the last few years, the authors have reported on imported Chinese comets from two other manufacturers, with somewhat similar construction characteristics, that also tended to explode violently upon their firing.[2–6] In each case, it was found that the malfunctioning white (or silver) comets had a high percentage of very fine magnalium (magnesium–aluminum alloy), used potassium perchlorate as the oxidizer, and had internal voids that could function as fire paths.

The comets in question for this article are of two different types: 3-inch solid cylindrical comets, and 3-inch tiger tail comets made by layering comet composition over an internal aerial shell.[1] While some cartons of both types of comets tended to experience the same explosive malfunctions, only the cylindrical comets were carefully studied and will be discussed in this article.

Test Firings and Comet Density Measurements

Initial field testing of the comets was conducted for the purpose of trying to identify which of four remaining cartons of the suspect comets demonstrated a tendency to explode upon firing. In this testing 10 comets from each case were test fired from paper mortars (which had been inspected to confirm that they had smooth interiors and were without obstructions). In these firings, almost all of the 40 comets functioned without a problem. Only one comet exploded violently within its mortar, and three other comets broke apart or had unusually short burn times. All four of the malfunctioning comets were from the same case. Because of the limited number of test firings from this suspect case, another 10 comets from that case were test fired. This time, again only one comet exploded violently within its mortar, and two more malfunctioned less violently. At this point the field testing was halted and the remaining comets from that case (and a few samples from two other cases) were repackaged and transported to the laboratory for further analysis.

It was suspected that comet density might be one of the predictors that determine which comets were most likely to fail explosively. At the lab, before further test firings were conducted, all of the remaining 62 comets (52 from the suspect case and 5 each from two other cases) were disassembled. The density of each comet was determined using the measurement of its mass and physical dimensions. It was found that the comets' density ranged from 1.41 to 1.73 g/cm^3. Given the formulation for the comets (discussed below), the maximum theoretical density of the comets would be approximately 2.4 g/cm^3. Thus the porosity of the comets was found to be quite high, ranging from approximately 30 to 40%.[7]

Once the density of each remaining comet was established, it was ranked from least to most dense. In preparing for further test firings, 42 of the comets were reassembled, drawing most heavily from those test comets with the very highest and the very lowest densities. Of these 42 comets, eight were from two of the cases previously found to have comets that apparently performed well,[8] and 34 were from the case previously found to occasionally malfunction. Of these 42 test comets, four explosively malfunctioned in the mortar as they were being fired. All four of these were from the same case of comets previously found to malfunction occasionally. In terms of density, two comets were among the very lowest density (i.e., the most porous), one had a mid-range density and one comet was from the group having higher density. While these results are somewhat consistent with the suggestion that density is a factor in determining which comets will malfunction, it is quite far from demonstrating that result to an acceptable degree of certainty.

It terms of establishing the cause of these comets' explosive malfunction, it should be noted that in each case the comet did not explode until it had traveled to nearly the top of the mortar. (For a photograph of a collection of the exploded mortars, see reference 9). Based on previous measurements of the dynamics of shell firings, this means that approximately 30 milliseconds elapsed between the ignition of the comets and their exploding.[10]

Chemical Analysis

Semi-quantitative chemical analyses were performed on comets from both the well-behaving and malfunctioning cartons. The results are summarized in Table 1. The binder in the comet composition was found not to dissolve in water, but it did dissolve in acetone. The amount of binder was determined using simple gravimetric methods. The binder solution was fairly reddish brown in color, suggesting the possibility that it was red gum based; however, the exact nature of this non-aqueous binder was not determined. After the binder was removed from the composition, the oxidizer was dissolved in water, and the amount again determined gravimetrically. The nature of the oxidizer was established using a combination of chemical spot testing and X-ray spectroscopy.[11] The amount of the remaining ingredients (almost exclusively metals) was determined by weighing. As part of a microscopic examination of the remaining ingredients, there appeared to be a trace quantity of charcoal (tiny black particles) mixed with the obviously metal particles. X-ray analysis revealed that the metals were almost exclusively aluminum and magnesium.[12] Further X-ray analysis performed in conjunction with electron-microscopic imaging, found that the metals were a combination of aluminum and magnalium (approximately a 50:50 alloy of aluminum and magnesium).

Table 1. Approximate Chemical Formulations of the Test Comets.

Ingredient	Percentages[a] Well-Behaved	Percentages[a] Mal-functioning
Potassium perchlorate	40	40
Aluminum	30	30
Magnalium (50:50)	15	20
Binder (non-aqueous)[b]	15	10
Charcoal	Trace	Trace

a) Percentages are approximate and are reported to the nearest 5%.

b) Based on the amount, it seems likely that the binder also functioned as an additional fuel.

The metal fractions from the compositions of the two groups of comets were subjected to a sieve analysis to determine their mesh fractions (i.e., the range and distribution of particle size). This was followed by an X-ray spectroscopic analysis to determine the ratio of aluminum to magnalium alloy in each mesh fraction. The results of these analyses are shown in Table 2.

The chemical analysis found two important differences between the apparently well-behaving comets and those tending to malfunction explosively. The first difference is in regard to metal content. While both types of comets had high percentages of very fine magnalium, the comets tending to explosively malfunction had a higher percentage of magnalium (approximately 1/3 more) and a higher percentage of that magnalium was finer than 400 mesh (see again Tables 1 and 2). The result is that the composition of the malfunctioning comets had nearly twice as much of the –400 mesh magnalium, as compared to the apparently well-behaved comets. The second difference

Table 2. Sieve Analyses of the Metal Fractions of the Comet Compositions.

Mesh Range (US Std.)	Mass Percent[a] in the Well-Behaved Comets		Mass Percent[a] in the Malfunctioning Comets	
	Aluminum	Magnalium	Aluminum	Magnalium
+60	30	0	45	0
60–100	35	0	40	0
100–200	30	5	15	0
200–400	5	30	0	15
–400	0	65	0	85

a) Percentages are approximate and are reported to the nearest 5%.

between the two batches of comets is in regard to binder content. While both types had relatively high percentages of binder, the apparently well-behaved comets had approximately 50 percent more binder than those comets tending to explosively malfunction. (The potential relevance of these differences will be discussed below.)

Microscopic Analysis

Small solid pieces to comet composition were taken from comets from the two groups (those apparently well behaved and those tending to explosively malfunction). These samples were mounted and sputter coated with gold in preparation for inspection using a scanning electron microscope. Figure 1 presents a pair of images of the typical internal structure of the two types of comet samples. The pieces of composition from the apparently well-behaved comets (see the upper micrograph in Figure 1) were found of have the appearance of being somewhat loosely bound and occasionally had fairly large void spaces. In comparison, the pieces of composition from the occasionally malfunctioning comets (see the lower micrograph in Figure 1) have an even more loosely bound appearance and significantly more and larger void spaces.

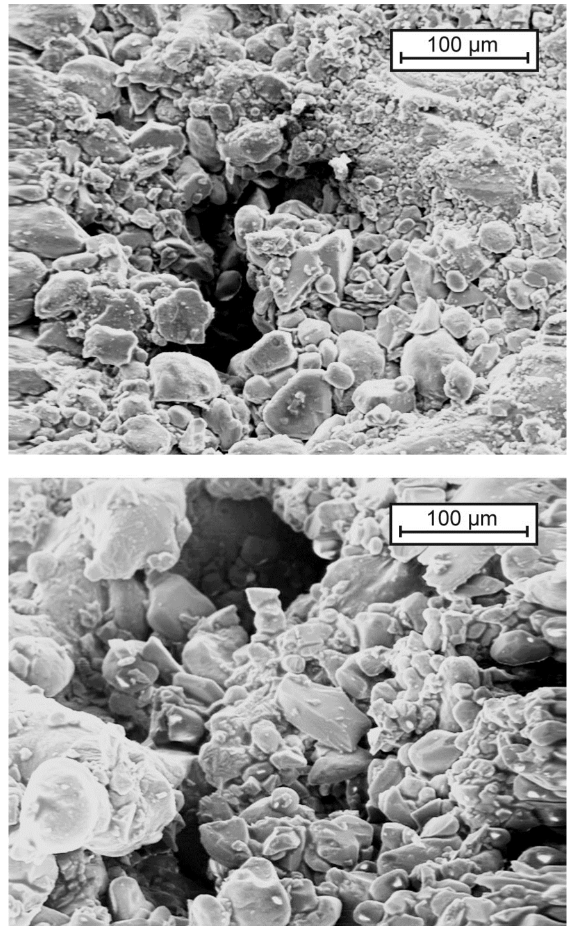

Figure 1. A pair of electron micrographs (200X magnification) comparing the typical internal structure of comet samples from the apparently well-behaved comets (above) and those tending to explosively malfunction (below).

Other Testing

Standard fall-hammer impact sensitiveness testing of the comet composition was performed after it had been finely ground using a mortar and pestle. It was found that the comet composition was relatively insensitive to impact when compared with some other commonly used comet compositions. Thus the malfunctions would not seem to be associated with the impact sensitiveness of the comets.

Because the chemical composition of the comets was similar to that of flash powders (which tend to be cap-sensitive) a standard cap-sensitivity test was performed, using a number 8 detonator. While in this single test, the comet did ignite, it merely burned and did not explode.

Discussion

The comets being studied in this instance had construction characteristics in common with the two previously investigated examples of white or silver comets that tended to occasionally malfunction explosively inside their mortar as they were being fired. In each case the comets: 1) contained a high percentage of very fine magnalium, 2) used potassium perchlorate as their oxidizer, and 3) had a significant number of substantially large internal voids. The relevance of the use of a combination of very fine magnalium (–400 mesh) and potassium perchlorate is that it would potentially constitute being a flash powder, if not tightly cemented into a solid mass. The relevance of the internal void spaces is that they can act as fire paths to carry the burning reaction quickly into and throughout the mass of the comet. In combination, these factors can cause the comet to function explosively after a very short delay during which time the burning reaction is accelerating through the mass of the comet. The process by which this can happen is explained more completely in reference 13, which discusses so-called aerial shell detonations or violent in mortar explosions, VIMEs.

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End Notes and References

1) As part of the agreement for supplying a substantial number of the suspect comets for testing, the manufacturer's name is being withheld. The authors found this to be acceptable because: a) the comets were imported into the US more than 2 years ago, b) it would seem that these particular comets (and possibly one other batch imported at the same time) were the only ones to experience the malfunctions, and c) it is unlikely that any supplies of these suspect comets currently exist to potentially produce an accident.

2) "'Impossible' and Horrific Roman Candle Accident", K. L. Kosanke, G. Downs and J. Harradine, *Fireworks Business*, No. 225, 2002; *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 6 (2001 and 2002),* 2005.

3) "Roman Candle Accident: Comet Characteristics", K. L. & B. J. Kosanke, G. Downs and J. Harradine, *Fireworks Business*, 228, 2003; *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 7 (2003 and 2004),* 2006.

4) "WARNING: Serious Product Malfunction", K. L. Kosanke, *Fireworks Business*, No. 232, 2003; *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 7 (2003 and 2004),* 2006.

5) "Report on the Initial Testing of Suspect Tiger Tail Comets", K. L. Kosanke, *Fireworks Business*, No. 233, 2003; *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 7 (2003 and 2004),* 2006.

6) "Further Report on the Testing of Suspect Tiger Tail Comets", K. L. and B. J. Kosanke, *Fireworks Business*, No. 237, 2003; *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 7 (2003 and 2004),* 2006.

7) What causes comets, or any compacted pyrotechnic composition, to have a density less than its maximum theoretical density is the presence of internal void space. The percentage of the volume occupied by these void spaces is described as a material's porosity. When the amount of void space is large, there is a tendency for the voids to become interconnected. When a significant number of the voids are interconnected, it will be possible for gas to penetrate significantly into the material, and the material is described as being permeable. In terms of a solid mass of pyrotechnic composition, its permeability is important because it will accelerate the burn rate of the composition. If the accelerated burn rate is sufficiently great, it may be possible for the burning to transition into an explosion. (For a further discussion, see reference 13.)

8) The comets are described as "apparently" performing well, because while none were found to explosively malfunction, based on their overall construction characteristics and the relatively small number tested, it cannot be assured that none of these would seriously malfunction.

9) "The Effect on Mortars of Explosions within Them", K. L. and B. J. Kosanke, *Fireworks Business*, No. 251, 2004; *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 7 (2003 and 2004),* 2006.

10) "Typical Aerial Shell Firing Time Sequence", K. L. and B. J. Kosanke, *Fireworks Business*, No 252, 2005; *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 8 (2005 to 2007),* 2009.

11) X-ray spectroscopy established that the oxidizer included potassium and chlorine in a ratio of approximately one to one. Spot testing revealed that the oxidizer was not potassium chlorate and that it was potassium perchlorate.

12) X-ray spectroscopy of a bulk sample of the metals found there to be small amounts of copper, zinc and iron present in addition to the aluminum and magnesium. Further X-ray analysis performed in conjunction with imaging individual particles using an electron microscope found that the minor ingredients were associated with only the aluminum metal particles, as some type of alloy.

13) "Hypotheses Regarding Star-Shell Detonations," K. L. and B. J. Kosanke, *Journal of Pyrotechnics*, No. 14, 2001; *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 6 (2001 and 2002)*, 2005.