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Roman Candle Accident: Comet Characteristics

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*[**Authors' note**: This article includes a number of notes with ancillary information. This information is not essential to the primary purpose of this article, and frequently interrupting one's reading of the main text to read the notes may be a distraction. Accordingly, the reader might wish to initially ignore the notes, and then if additional information is desired, read any notes of interest.]*

This article is the second in a series addressing the nature, cause and course of a most horrific accident caused by a large-bore Roman candle.[1] These articles are offered in the hope that through a sharing of what was learned in this case, similar accidents might be avoided in the future.

Upon initially learning of the nature of this horrific accident, it was thought that the powerful explosion most likely had resulted from the use of flash powder or salutes in substantial quantity (size or number). It simply was not believed that Roman candles firing simple white-tailed comets[a,b] could possibly produce such an incredibly powerful explosion, even from Roman candles with a bore diameter of 2 inches (50 mm).[c] However, as a result of the initial investigation, it seemed likely that the Roman candles were indeed responsible. Subsequently, during the course of extensive testing of Roman candles from the same shipment as were involved in the accident, it became clear that these Roman candles did indeed malfunction explosively. Testing also demonstrated that these Roman candles, when confined in steel support tubes,[d] did have the ability to fragment the steel tubes and disperse those fragments at high velocity. (A summary of the testing is planned as additional articles in this series.)

What is so unusual about the Bray Park incident is that the pressure that developed inside the Roman candle tube rose to incredibly high values and rose to those levels at an incredibly high rate. For this general type of Roman candle, neither the pressures reached nor the rate at which they were produced would have been predicted. This is especially important because had only one of the two unexpected factors happened during the malfunction, the accident would not have occurred. Had the pressures risen rapidly but to a less catastrophic level, the steel pipe (if not the Roman candle tube, which itself was quite strong) would have successfully contained the pressure until the gases were safely vented up the mostly open bore of the Roman candle and through the gap between the candle and steel support tube. Had the pressures attempted to rise to catastrophic levels, but at a lower rate, then the gases would have had ample time to vent and the pressure would never have been able to reach a high level. In this case, what happened is that the pyrotechnic composition, in the form of the comets, acted very much more like a powerful explosive than merely a solidly compacted pyrotechnic composition. This article is a discussion of the unique set of characteristics of the comet stars thought to have allowed the production of such powerful explosions.

Characteristics of the Bray Park Roman Candle Comets

What seems to have happened in this case, to cause the rapid and catastrophic rise of pressure inside the Roman candle, is that its comets were produced in such a manner as to have an apparently unprecedented combination of three properties that acted in concert to provide their

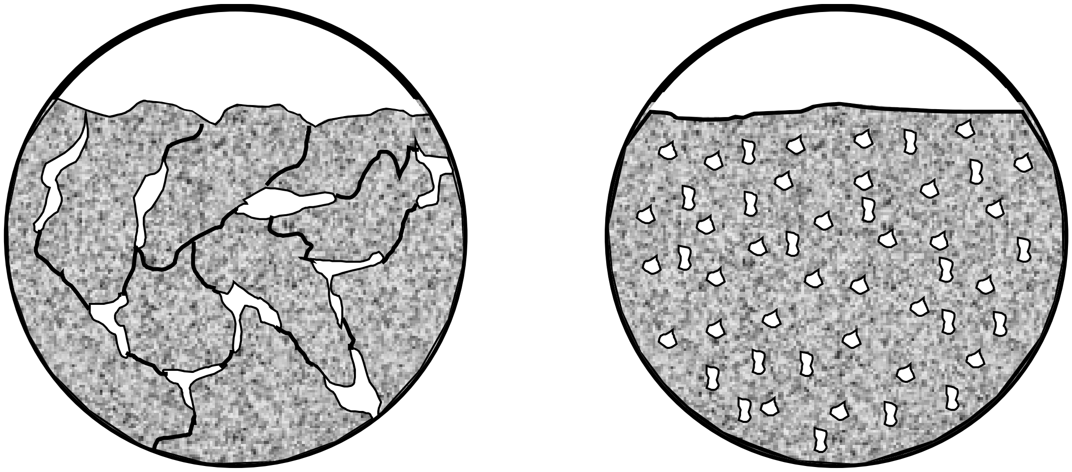

Figure 1. An illustration of the internal structure of the Bray Park white-tailed comets (left) and the normally expected structure (right).

unique explosive behavior. Had only two of these three properties been present in the comets, the accident would not have occurred as it did. Further, each of these properties ranged from being unusual to being extraordinarily unusual (if not unprecedented).

The first property of the comet that contributed to the cause of the accident is the manufacturer's use of a substantially higher-energy and more-reactive comet composition than is commonly used. For example, traditionally white-tailed comet effects were produced using relatively large particles of aluminum to produce sparks, plus charcoal and/or sulfur as the low-energy fuel, and potassium or barium nitrate as a low-energy oxidizer.[e] More recently granules of titanium are often used to replace the aluminum particles for spark production, with the bulk of the chemical composition continuing to be similar to Black Powder (gunpowder).[e] However, the Bray Park comets included the use of fine-grained magnalium[f,g] as a highly reactive metal fuel, plus the comets used potassium perchlorate as a more energetic oxidizer.[e] Normally, by itself, the use of a reactive and high-energy formulation would not cause a problem. However, in the presence of the other two unusual comet properties, the additional energy that was produced by this formulation and the additional speed with which the energy could be produced acted to both substantially increase the likelihood of an explosion occurring and to substantially increase the power of that explosion.[h]

The second property of the comets that contributed to the cause of the accident is that there needed to be some way for fire to sufficiently and nearly instantaneously penetrate throughout the interior of the comets. Normally such fire penetration is precluded because comets are made of tightly compacted and bound pyrotechnic composition. Thus, while there will always be some degree of porosity (tiny voids remaining within the composition), those voids are not sufficiently well connected to allow substantial intrusion of fire into the comet when it burns. What is so unusual with some of the Roman candle comets in this case is that they were permeable to a significant extent (i.e., their internal void spaces were not that tiny and they were sufficiently well connected such as to provide "fire-paths" into and through the comets' interior).[i] Figure 1 is an attempt at illustrating the difference between typical comets and those involved in the Bray Park accident. With the presence of many fire-paths into and through the comet, the time taken for the comet to burn can be reduced from several seconds down to a fraction of a second. That is to say its energy is released much more quickly and the potential for producing a powerful explosion is significantly increased.

The third property of the comets that contributed to the cause of the accident is that they were exceptionally strong structurally. Usually a Roman candle comet will be moistened with water and compacted to form a solid and reasonably hard pellet, bound together using something like dextrin. While this forms a solid mass when dried, if one were to scratch it, even with one's fingernail working sideways, one would soon make a shallow groove in the comet. One of the surprising properties of the Roman candle comets involved in the Bray Park accident was that they were incredibly hard and structurally strong. The comets were much more like rock or concrete than a normally bound and compacted pyrotechnic composition. The structural strength of the Roman candle comet is important because one thing that is needed, to cause a solidly compacted pyrotechnic composition to produce an explosion when it is burned, is that the burning pyrotechnic composition be strongly confined.[j]

The near total confinement of a burning pyrotechnic has two important effects. First, such confinement allows the pressure produced to rise significantly above atmospheric pressure. This rise in pressure, acts to significantly accelerate the speed of burning,[7] which acts to further increase the rate of pressure build-up. Thus the overall effect of such confinement of a burning pyrotechnic composition is to significantly reduce the time taken for its chemical energy to be released. The second effect of near total confinement is that when the pressure produced eventually exceeds the burst strength of the confinement, there will be an explosion as the confinement fails. However, in the case of the Bray Park comets, because of their structural strength, they provided their own strong confinement and can powerfully explode without the need for any <u>external</u> confinement.[k]

Discussion

Normally a Roman candle comet of the size of the Bray Park Roman candles, approximately 0.8 inch (20 mm) thick and 1.8 inches (45 mm) in diameter, takes several seconds to burn and release its chemical energy. However, in the case of the Bray Park Roman candle comets (with all three of the characteristics described above), instead of the energy being released slowly over an interval of several seconds, most of the energy manifested itself on a time scale probably less than (and possibly on a time scale substantially less than) a few milliseconds. The importance of this is that, while the total energy produced by normally-functioning and Bray Park comets is essentially the same, the power developed by such a malfunctioning comet is at least a 1000 times greater (and possibly much greater). As a result, in the case of the malfunctioning Bray Park Roman candles, even though the bore of the Roman candle tube was essentially unblocked, when one comet explodes, not much of the explosive pressure is able to be relieved by gases escaping up the essentially open bore of the Roman candle tube. Accordingly, the result of the explosion of a single comet within a Bray Park Roman candle can be the near simultaneous consumption (explosion) of all the other comets in the Roman candle. This combined explosive output is then sufficient to fragment the Roman candle tube and its supporting steel tube.

The unique and unexpected explosive performance of the Bray Park Roman candle comets was demonstrated in testing during field trials. This testing also provided partial confirmation that the cause of the malfunctioning Bray Park comets resulted from the combination of the three factors: their high energy composition, significant permeability and great structural strength. (The next article in this series will present a summary of the field trials.)

Conclusion

This article presented information on those characteristics of the Bray Park Roman candle comets thought to be most important in providing them with the ability to produce incredibly powerful explosions, even when completely unconfined. In the next article in this series, a summary of the testing undertaken by the Queensland Department of Natural Resources and Mines will be summarized. This testing clearly demonstrated the capability of Roman candles, in conjunction with their steel support tubes, to have produced the accident.

Ancillary Notes

a) The subject 2-inch (50-mm) Roman candles were imported into Australia early in 2000. Some 1.5-inch (38-mm) Roman candles, with identical labeling (considering their slightly smaller size) and of apparently identical construction, were imported into the US. (Photos of the labeling were included in the previous article.[1])

b) Many of the suspect Roman candles had been X-rayed, which revealed that the comets were solid with no internal structure (e.g., they were not crossettes). In addition, this was further confirmed when comets were extracted from the Roman candles, physically examined and broken apart to inspect their interiors.

c) Because the authors had not heard of another similar Roman candle malfunction, particularly with regard to having produced such a powerful explosion, inquires were made of more than ten researchers (mostly from government laboratories) from four countries with joint expertise in both pyrotechnics and fireworks. Those researchers were singularly of the view that they would not have predicted that a malfunctioning Roman candle was the cause of the accident at Bray Park. More specifically, prior to learning something about the testing of the comets in this case, these researchers each considered the malfunctioning of a Roman candle such as occurred at Bray Park to be virtually impossible, with no known previous occurrence.

d) The steel support tubes had an inside diameter of 3.00 inches (76 mm), a wall thickness of 0.14 inch (3.6 mm) and extended 19.7 inches (500 mm) up the length of the Roman candles. The Roman candles were 31.5 inches (800 mm) long and had an outside diameter of 2.48 inches (63 mm). Thus there was a relatively close fit of the Roman candle in the support tube, with the difference between the outside diameter of the candle and the inside diameter of the steel tube of 0.28 inch (7.1 mm).

e) Two examples of traditional (Black Powder and aluminum) white comet formulation are presented as 1 and 2 in Table 1. Two more recent formulations (Black Powder and titanium) are presented as 3 and 4. The high energy formulation used in the Bray Park white-tailed comets is also shown. (For convenience in preparing the table, the particle size and shape of the ingredients have not been specified for any of the formulations.)

Table 1. Example Formulations for White Comets.

	White Comet Formulations				
	Traditional		Recent		Bray
Ingredient	1	2	3	4	Park
Potassium nitrate	40	45	64	18	
Charcoal	20		13		
Sulfur	10	10	9	4	
Antimony sulfide	5				
Black (gun) Powder		5		50	
Aluminum	18	40		3	
Titanium			9	18	
Boric acid				1	
Dextrin	7	+5	5	6	
Potassium perchlorate					50
Magnalium[f,g]					35
Acaroid-type resin					11
Unidentified					4
Reference	2	3	4	5	6

f) The magnalium used in the Bray Park white-tailed comets was quite fine grained, with the median particle size averaging approximately 40 microns (a little finer than 325 mesh). Also the particle size distribution of the magnalium was quite varied, even within the comets of a single Roman candle. For example in one Roman candle in which four of the comets were analyzed, the median particle size differed by as much as a factor of two, ranging from 26 to 53 microns. Further in the case of the magnalium with the 26 micron median particle size (which was approximately 600 mesh), 15 percent of that magnalium was less than 12 microns (1200 mesh).

g) The alloy ratio of this magnalium (Mg:Al) was approximately 25:75.[6]

h) Power is defined as the time rate of energy production. Thus the speed at which a chemical reaction takes place (i.e., the rate of energy production) is important in determining the power of an explosion. Even if the Bray Park comets had produced no more energy than commonly used formulations, but they produced that energy more quickly, the power output would be greater.

i) During the course of the Department of Mines investigation, some of the Bray Park Roman candles were broken apart for the purpose of examining their interiors. Those examinations revealed the presence of internal channels when viewed under a low-power microscope.

j) Perhaps a good example of the need for confinement in this case is a pipe bomb, where one might take large masses (chunks) of a compacted pyrotechnic composition, put them in a pipe, seal the pipe, and ignite the contents inside the tightly closed pipe to produce a powerful explosion. However, if one of the end caps of this pipe bomb were left off, such that the pipe is open on one end, when its contents are ignited they will simply burn and vent the combustion gases out the open end of the pipe without exploding.

k) By way of emphasizing the incredible magnitude of some of the explosions that occurred, note that nothing near this same level of explosivity would have been produced had the tests been conducted using the same amount (approximately 60 g) of a firework flash powder similarly burned in the open on a flat surface.

References

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7) K. L. and B. J. Kosanke, " Control of Pyrotechnic Burn Rate", *Proceedings of the 2nd International Symposium on Fireworks*, 1994; also in *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 3 (1993 and 1994)*, Journal of Pyrotechnics, 1996.