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"Skip Burning" of Visco Fuse

K.L. and B.J. Kosanke

In late December 1978 more than 100 serious injuries were reported in eastern Kentucky, apparently the result of defective visco fuse.[1] The defective fuse had been used by a manufacturer of M-80's and other illegal consumer devices. These devices "exploded as soon as they were lit", apparently while still being held in the hand. While the authors' interests were peaked by this report, it was not possible to investigate the cause of the malfunctioning fuse because none was available for testing. Many years later, while discussing the accidents at the 1989 PGI Convention, Eldon Hershberger said that he had a small amount of fuse dating back to approximately that time, and the fuse had an unreliable burn rate. He stated that the fuse generally burned normally, but every once in a while the burning seemed to instantly advance ½ to 1 inch. He had purchased the fuse from a hobbyist supplier in the late 1970's. This sounded like it might be the defective fuse we wished to have for testing. Eldon was kind enough to supply two short lengths for evaluation.

Before undertaking the study of the suspect fuse, it seemed appropriate to first study the performance of well-behaved visco fuse, both when burned normally and when subjected to various external influences (temperature, pressure, and physical abuse). The results of this study were reported a few years ago.[2] Although work on the suspect fuse was completed shortly thereafter, and the results reported at the 1990 Western Winter Blast, this article was not completed until now.

Figure 1 illustrates the construction of visco fuse, also referred to as hobby fuse or cannon fuse. The fuse powder core contains about 25 mg/cm of powder. Generally within the core is a single thread, whose presence facilitates the uniform flow of powder during manufacturing. Surrounding the powder core are two layers of thread, wrapped in opposite directions. The inner wrap is wound with the threads touching one another, completely and tightly encircling the powder core. The outer wrap often consists of fewer threads with gaps in between. The threads constitute much of the bulk of the fuse, keep the powder core intact, and provide resistance to side ignition. The exterior of the fuse is coated with nitrocellulose lacquer (typically containing green or red dye), which provides water resistance to the fuse.

A close examination of the exterior of the suspect fuse did not reveal problems with its construction. The diameter was consistent, suggesting that the amount of powder in the core was approximately constant and that there was a full complement of inner threads. The lacquer coating was

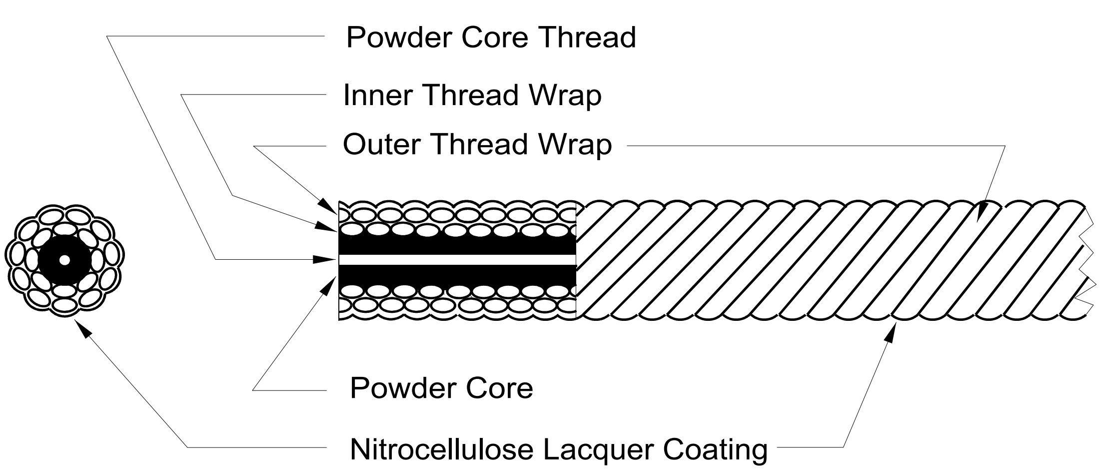

Figure 1. Drawing illustrating the general construction of visco fuse.

Table 1. Fuse Powder Weight Percentages by Sieve Mesh Fractions.

	Percentages for Mesh Fraction					
	+40	40–60	60–80	80–100	–100	–60
Ensign-Bickford (Very Old / Red) (Military Production)	33	32	14	10	12	
American Visco Fuse (Recent Production)	14	39	17	12	17	
Average of E.B. and Amer. Visco Fuse	24	35	15	11	15	41
Suspect Fuse Sample #1	48	31	11	6	4	
Suspect Fuse Sample #2	47	32	10	6	5	
Average Suspect Fuse Samples #1 & #2	48	31	11	6	4	21
1/8 in. “Instantaneous” Shell Leader	66	27	3	2	3	
1/4 in. “Instantaneous” Shell Leader	83	9	2	1	5	
Aver. “Instantaneous” Shell Leaders	74	18	2	2	4	8

present in a typical amount.

Since the supply of suspect fuse was limited, it seemed prudent not to destroy a significant amount of it before the nature of its defect was determined. Accordingly, the first test was to X-ray the fuse. It was hoped that this would allow a close examination of the powder core without sacrificing any fuse. Although several attempts were made, this approach was not successful. The powder core was almost invisible. The atomic number of the atoms making up the powder core and those in the threads and nitrocellulose were not sufficiently different to provide the needed X-ray contrast.

In order to examine the powder in the suspect fuse, several inches of fuse were sliced longitudinally and the powder retrieved. The physical appearance of the fuse powder seemed to be somewhat coarser than normal. For a comparison, fuse powder was collected from some properly behaving American Visco Fuse.[3] This powder appeared to be of finer granulation than the suspect fuse powder. Photo 1 provides a visual comparison of the fuse powders. To quantify the difference, enough fuse powder was collected from both types of fuse for a sieve analysis. Because it was unknown whether the powder granulation was constant along the length of the fuse, short samples were taken every few inches. Approximately 0.35 g of powder was collected from one piece of the suspect fuse, and about 0.42 g of powder was collected from normally behaving American Visco Fuse.

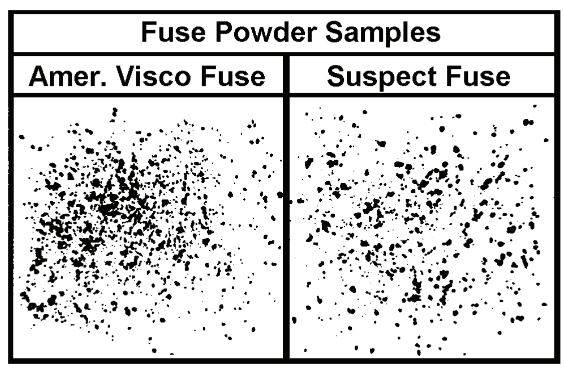

Photo 1. Photograph of fuse powder extracted from the suspect fuse (right) and normally burning fuse (left).

With less than half a gram to work with, screening with normal 8-inch diameter laboratory sieves could introduce significant errors due to lost or trapped powder. Accordingly, special small sieves, approximately 3/8-inch in diameter, were fabricated with 40, 60, 80 and 100-mesh screens. Upon sieving, there was an obvious difference in the granulation of the two powder samples. As

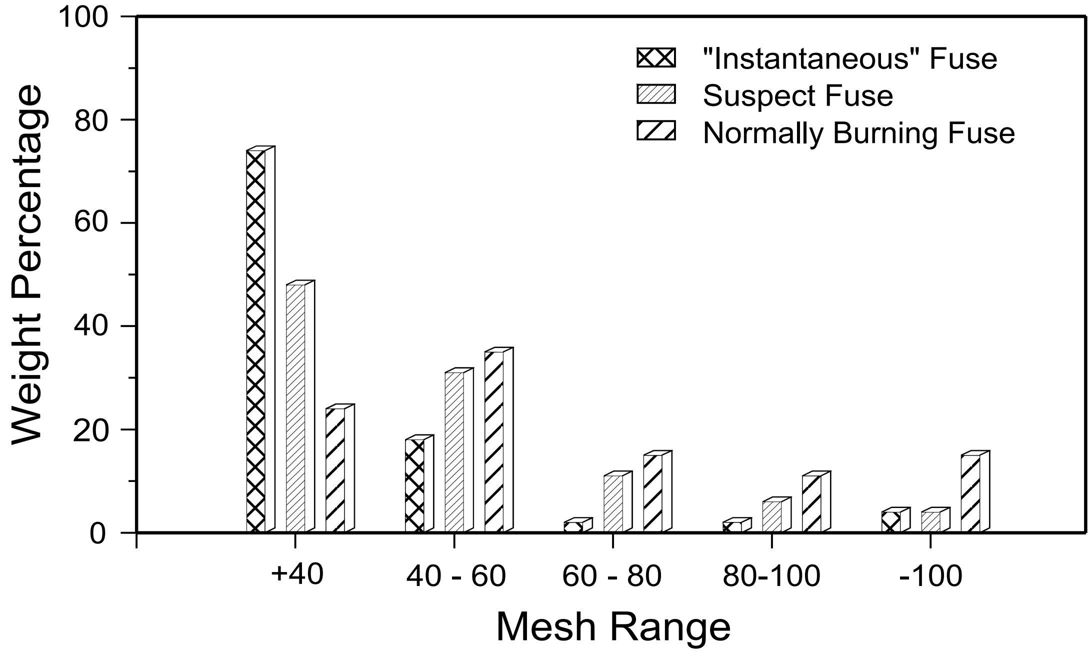

Figure 2. Bar graph of fuse powder weight percentages as a function of mesh fraction.

confirmation of the difference, fuse powder was also collected from a sample of old Ensign-Bickford visco that had been made for the military, and also from the second piece of suspect fuse. The results for the four fuse samples are listed in Table 1 and graphed in Figure 2. The well-behaved fuses had approximately twice the percentage of –60 mesh powder. However, it was still necessary to consider whether this was actually the reason for the erratic performance of the suspect fuse.

For fuse to burn at a constant slow speed, it must experience parallel burning as opposed to propagative burning. (See Reference 4 for a more complete discussion of parallel and propagative burning.) When a gas generating pyrotechnic material consists of uniformly large granules, such that fire paths exist between the grains, high speed propagative burning will take place. As the size of the grains is reduced and the range of particle size is broadened, the tendency for slow parallel burning is increased. Accordingly, the difference in granulation observed in the fuse samples could be the reason for their different behavior.

As partial confirmation of this theory, two additional fuse powder samples were examined. For a year or two in the mid-1980's, some reloadable consumer fireworks shells were imported with a nearly instantaneous fuse that was about 1/8 inch in diameter. This fuse appears much like thin time fuse, and was made with a compressed paper sheath around a powder core, with an outer wrap of threads holding it together. At about the same time, some 2½- and 3-inch display shells were imported with a larger (1/4-inch) version of the same fuse (See Photo 2). Powder was collected from samples of these two types of instantaneous fuse and then analyzed to determine the particle size distribution. These results are also presented in Table 1 and Figure 2. Note that the ratio of –60 mesh powder is approximately 4:2:1, for the normally behaving fuse, the suspect fuse, and the instantaneous fuse, respectively. Also, particle size

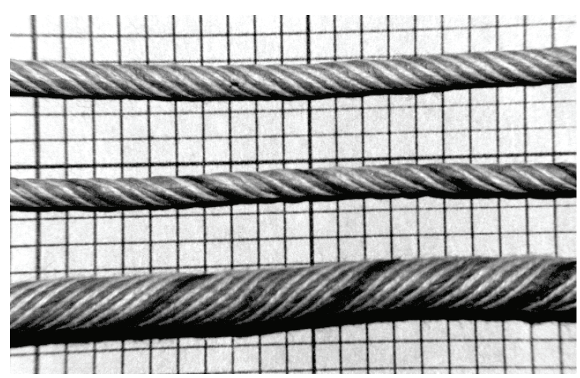

Photo 2. Photograph of three samples of "Instantaneous" fuse shell leaders.

is more evenly distributed for the normally performing fuse. The greatest and least percentages of the mesh fractions are 35 and 11%, respectively, whereas, the greatest and least are 48 and 4% for the suspect fuse, and 74 and 2% for the instantaneous fuse. This tends to support the theory that the erratic burn rate reported for the suspect fuse was the result of the coarser granulation and more narrow particle distribution size of its fuse powder.

Recall that, because of the limited supply of the suspect fuse, no burn tests had yet been performed. Now, with a viable theory in hand, the time seemed right to sacrifice much of the remaining fuse in a series of burn rate tests. A collection of 14 five-inch long fuse segments were prepared. Each length of fuse was ignited and its burning closely observed. The burn time and nature of burning were recorded for each piece of fuse. The suspect fuse demonstrated two different types of burning, what might be referred to as "normal-burning" and "skip-burning". Normal burning is slow and constant-rate burning, as expected for visco fuse, whereas skip-burning is a near instantaneous advance of the apparent burning surface in the powder core. Typically these advances would consume 1/2 to 3/4 inch of fuse. Normal burning predominated, with a skip-burn occurring on average about once every five inches. Each skip-burn was accompanied by a noticeable "jetting" sound, and occasionally the fuse would be propelled through the air, if it was not held in place.

In the parlance of burn types, the normal burning would seem to correspond to parallel burning and the skip-burning would seem to be propagative burning. Apparently the powder in the suspect fuse contains sufficient fine grained material, such that a large percentage of the fire paths are reasonably well blocked, and, generally the burning proceeds normally. However, occasionally, enough fire paths are sufficiently open to allow a short portion of the suspect fuse to skip-burn, a temporary transition to propagative burning. By contrast, in the instantaneous shell leader fuse, it would seem that the amount of fine grained material is so low, that it always burns propagatively.

At this point some consideration was given to how to prove this theory. One approach would have been to prepare an amount of black powder, some with the granulation matching that in well-behaved fuse and some with a lower than normal amount of fines like in the suspect fuse. Then both powder samples could be made into fuse, to determine how it burns. In this way, the only difference in the two types of fuse would be the granulation of its fuse powder. If the first behaved normally and the other skip-burned, this would support the theory. Another approach would have been to eliminate the possibility that there was something strange in the chemical composition of the powder core in the suspect fuse.

However, neither of these approaches was taken. In part, this was because of the cost involved, but mostly it was because information provided by individuals in the fuse-making trade, tended to support the theory. First, it was learned that it is common to add a mixture of fine-grained potassium nitrate, charcoal and sulfur to commercial black powder. (This was confirmed by microscopic inspection of a sample of fuse powder.) The reason given for using the fine-grained rough black powder was not one of economics but to lower the burn rate of the fuse. Then it was learned that, at the time of the M-80 injury incidents, the reason for the malfunctioning of this particular fuse was rumored to be well known, at least to a few industry insiders. As the story goes, the fuse maker normally used a mixture of different granulations of commercial black powder. Unfortunately, one day the person making fuse ran out of the mixed powder and substituted some coarser grained commercial powder. Apparently, by the time the skip burning problem came to light, the fuse had been sold, and the M-80's had been made and distributed. With this information as confirmation of the theory advanced above, there seemed little reason to proceed with further investigation.

At this point it may be appropriate to address the reasons for writing this article. First, it is hoped that the story is at least a little interesting. Second, it serves as a good example of parallel and propagative burning, how they come about, and the important consequences that can result when unexpected burn type transitions occur. Finally, perhaps it illustrates the wisdom expressed in the warning "Do Not Hold in Hand!"

The authors wish to gratefully acknowledge Eldon Hershberger for providing the suspect fuse samples, Stan Addison for X-raying the fuse, and Quinton Robinson, Jerry Gitts and others for information about visco fuse making.

References

1) AP wire service release dated Dec. 26, 1978, Printed in *American Pyrotechnist*, No. 2, Feb. (1979).

2) K.L. and B.J. Kosanke, "Burn Characteristics of 'Visco' Fuse", *PGI Bulletin*, No. 75 (1991).

3) American Visco Fuse, 11984 N. Telegraph Rd., Carleton, MI 48117.

4) K.L. and B.J. Kosanke, "Parallel and Propagative Burning", *PGI Bulletin*, No. 78 (1992).