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Burn Characteristics of Visco Fuse

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From time to time there is speculation regarding the performance characteristics of visco fuse under various conditions. This article presents the results of a brief study of this topic.

The fuse for this study was purchased from American Visco Fuse[1] in 1989. While it is likely that visco fuse from other manufacturers will perform similarly, that has not been verified.

Typical Fuse Burning Statistics

Before attempts were undertaken to establish the effects of temperature, coverings and abuse on the burn rate of visco fuse, it was felt that first a check should be made to determine to what extent the burn rate varies along sequential pieces of fuse. To accomplish this, 204 pieces of fuse were cut from a new roll of visco fuse. Each piece of fuse was five inches long, with an uncertainty of approximately ±⇄ inch. The pieces of fuse were kept in their original sequence for testing. The test of each piece of fuse consisted of igniting it and measuring the time from ignition until the fire spit from the opposite end. All tests were performed at a constant temperature of about 50 °F, and the fuse had been maintained at that temperature for more than a day.

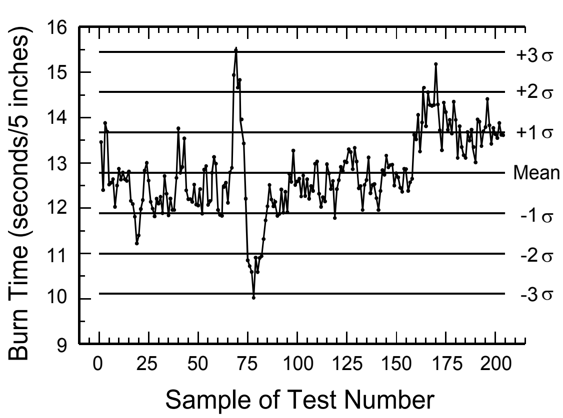

Figure 1. Burn times of sequential five-inch segments of visco fuse.

Figure 1 is a graph of burn times for the sequential fuse segments. Much of the data appears, as might be expected, relatively small, mostly random, fluctuations in burn times occurring from segment to segment. These fluctuations could be the result of actual small changes in burn rate along the length of fuse. However, they could be, and to at least some extent must be, the result of small experimental errors in timing the burning fuse. The average burn time was calculated and found to be 12.8 seconds per 5 inches; this corresponds to a burn rate of 0.39 inches/second (2.6 seconds/inch). The coefficient of variation of burn time was found to be 6.9 percent.[(a)]

The above not withstanding, there are features in Figure 1 that must result from actual changes in fuse burn rate. One occurs in the range of segments 70 to 90. Initially the segments burn increasingly slower, then progressively faster, and finally return to normal. The chance that this cycle of burn rate changes was a normal statistical fluctuation is approximately one in a hundred billion. Thus one must conclude that it represents a systematic change in burn rate, resulting from a change in some characteristic of the fuse. A second feature seen from segments 90 to 204, is even less likely to be merely a statistical fluctuation. Here the first 70 segments all tend to burn about one-half standard deviation fast, then the next 45 all tend to burn about one standard deviation slow. As before, this must result from an actual change affecting the burn rate of the fuse.

Because the data contains features that definitely are not typical random fluctuations, the

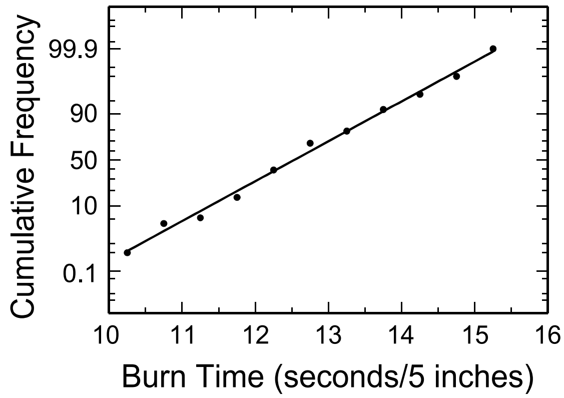

Figure 2. Cumulative frequency graph of burn times reported in Figure 1.

data was tested to determine the extent to which it deviated from a statistically "normal distribution." This was done by plotting cumulative frequency on probability paper, shown in Figure 2. When a distribution is normal, its cumulative frequency graph will be a straight line[2]. As can be seen, there is very little departure from normality. Accordingly, the coefficient of variation reported above can be viewed as a fairly accurate predictor of the probability of observing various burn rates, providing the sample set is large enough.

Because relatively few measurements were made for each condition investigated in this study, a procedure was required in order to limit the adverse effect of any small systematic changes in burn rate. The method used was to distribute sequential fuse segments among the groups of fuse pieces for each series of tests. For example, suppose one test series consists of sets of ten measurements under each of three different conditions. In this case, three groups of ten fuse segments would be assembled as follows. The first segment would be placed into the first group, the second sequential segment into the second group, and the third segment into the third group. Similarly, fuse segments 4, 5 and 6 would be placed into groups 1, 2 and 3, respectively. This process would continue until each group had 10 segments. In this manner, by distributing sequential fuse segments between the groups, any effect caused by systematic changes in fuse performance along the roll would be minimized. This general procedure was followed for each of the tests reported in this article.

Effect of Temperature

Changes in ambient temperature alter the burning characteristics of pyrotechnic materials. One effect is that, as the temperature is increased the burn rate also increases[3]. This is because less thermal energy is needed to raise unburned composition to its ignition temperature. This means that less time is required to raise unburned material to its ignition temperature, and that manifests itself as an increase in burn rate.

The effect of ambient temperature on visco fuse burn rate was investigated. In preparation for these measurements, five groups of ten fuse segments (each five inches long) were assembled as described above. Each group was placed in a separate container and the temperature of the container and fuse segments was raised or lowered to one of the values desired for testing. Once certain that the container and fuse had reached the desired temperature, the burn rate for each fuse segment was measured. To minimize changes in fuse temperature during measurements, the tests were conducted under ambient temperature conditions approximately equal to that of the fuse. Further, only one piece of fuse at a time was removed from its container and its burn time measured immediately. Without delay, the next piece of fuse was measured, and so on, until all ten fuse segments in that temperature group had been measured. The re-

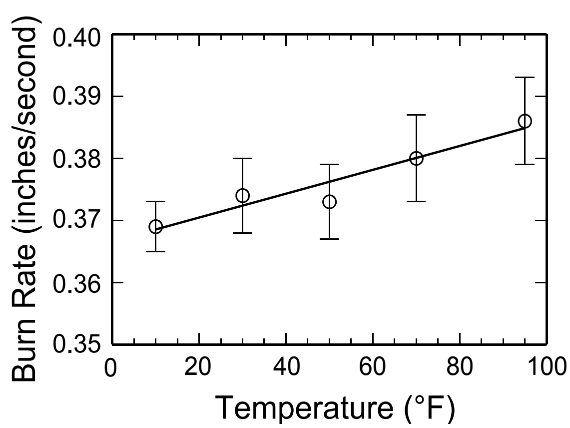

Figure 3. Temperature dependence of visco fuse burn rate.

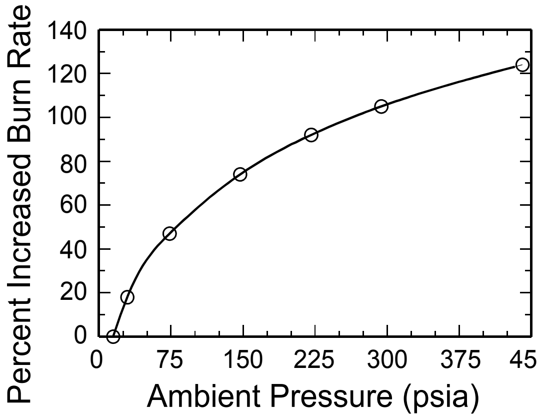

Figure 4. Functional relationship between pressure and black powder burn rate.

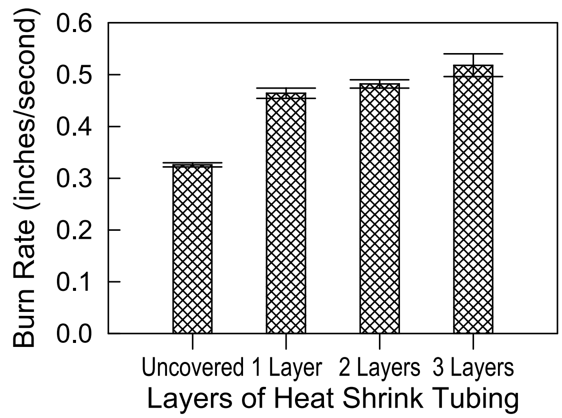

Figure 5. Burn rate variation as a result of tightly covering visco fuse.

sults of the temperature dependence tests are shown in Figure 3. The error bars shown are 1σ standard errors.[(b)] The slope of the line fit to the data is the change in burn rate as a function of temperature, which is 1.92 x 10^{-4} inches per second per degree Fahrenheit. As a result of this determination, two things seem obvious. First, burn rate has only a slight temperature dependence (i.e., extrapolating to an increase of 100 °F only results in about a 5% increase in burn rate). Second, the technique of distributing fuse segments, in order to minimize the sequence dependent changes in burn rate described in the section above, seems to have worked well.

Effect of Fuse Coverings (Pressure)

When visco fuse burns, the pressure at the burning surface of its powder core, will be somewhat greater than atmospheric pressure. This results from the temporary confinement of the gaseous combustion products by the thread and lacquer coating of the fuse. Anything that alters the degree of confinement, such as gluing or taping the fuse, must then be expected to alter the pressure at the burning surface. It is known that changes in pressure alter the burning characteristics of pyrotechnic materials.[3,4] This is because, as pressure increases, the thermal density of the flame increases. The flame becomes smaller, hotter, and is held closer to the burning surface. The effect is to increase the efficiency of the feedback mechanism for thermal energy, and this increases the rate of burning.

Figure 4 illustrates the effect of pressure on the burn rate of Black Powder (derived from information in Reference 4). Typical of most pyrotechnic materials, black powder burn rate obeys the general relationship:

$$R = A \cdot Pb \qquad \text{Eq. 1}$$

where R is linear burn rate, P is pressure, and A and b are constants[3]. For black powder, when R is in centimeters per second and P is in atmospheres, the constants A and b are 1.21 and 0.24, respectively.[3,4]

The effect of coverings on the burn rate of visco fuse was investigated. In preparation for these tests, four groups of ten fuse segments (each five inches long) were prepared as described above. The method chosen to cover the fuse segments was to apply layers of heat shrink tubing, using as high a temperature as possible without injuring the tubing or igniting the fuse. This method was selected because it was felt to be reproducible and similar to the effects produced by taping or gluing. In addition to one group of fuse segments with no added covering, groups were prepared with one, two and three layers of heat shrink tubing. After all the fuse was allowed to come to about 50 °F, each of the four groups was burned and their burn times recorded. The results of these tests are shown in Figure 5. Covering the fuse with 1, 2 and 3 layers of heat shrink tubing produced increases of 42%, 48%, and 59% in burn rate,

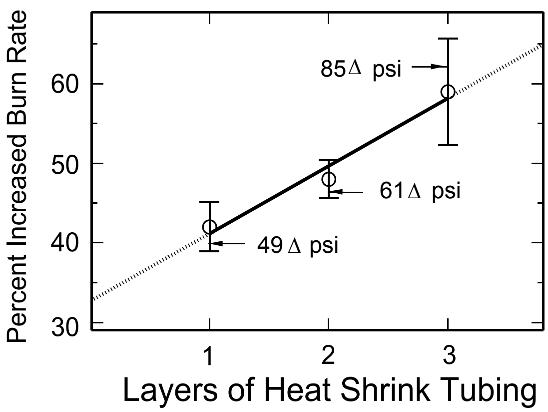

Figure 6. Burn rate variation and corresponding effective pressures as a result of tightly covering visco fuse.

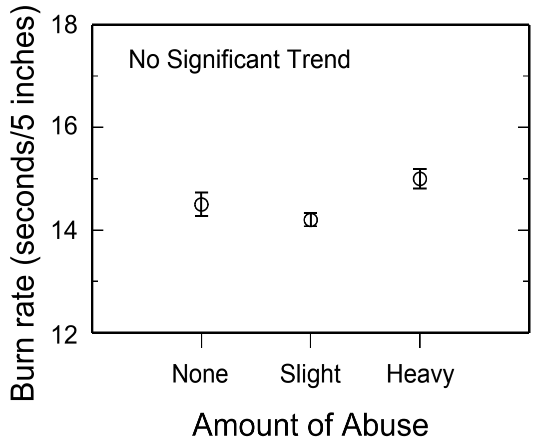

Figure 7. Effect of physical abuse on the burn rate of visco fuse.

respectively. The error bars are 1σ standard errors.[b]

It might be of interest to estimate what increase in pressure at the burning surface must have been produced by the layers of heat shrink tubing. For the purpose of this discussion, assume that the pressure acting on the burning surface is one atmosphere (14.7 psi) when there is no added covering on the fuse. With this assumption Figure 4 can be used to determine the pressure that corresponds to the increased burn rates for the covered fuse. The percent increase in burn rate and the effective increases in pressure for 1, 2 and 3 layers of heat shrink tubing is shown in Figure 6. Note that the reported pressures seem reasonable; this is important because it tends to confirm that the mechanism producing the increased burn rate is the same one described in Equation 1.[c]

Effect of Fuse Abuse

It is possible that mild to moderate damage to the fuse could produce significant changes in its burn rate. To examine this, a brief series of tests were undertaken. In preparation for this study, three groups of ten fuse segments (each five inches long) were prepared as described above. The fuse segments in the first group were left in their original condition. The second group received light abuse by repeatedly drawing each segment back and forth over an 11/16-inch radius edge, flexing it about 180° each time. After each pair of passes, the fuse was rotated slightly so as to bend the fuse in a new direction each time. The process was continued for a total of 20 passes. Some of the lacquer coating flaked off, but there was no significant damage to the outer thread covering. It is felt that this amount of damage was as much as would ever occur during normal use of the fuse. The third group received heavy abuse by following the same procedure used for group two; however, the edge used had a radius of less than ⇄ inch. This time, at the completion of the abuse, all the lacquer had been worn away and the outer threads were becoming significantly frayed. It is felt that this amount of damage greatly exceeded that which would ever occur during normal use. Once the fuse segments were allowed to come to about 50 °F, each segment was burned, and its time recorded. Figure 7 presents the average results of these trials. The error bars are 1σ standard errors.[b] As can be seen, there was no effect of abuse on burn rate. In addition, it is interesting to note there was a high degree of consistency among the individual fuse segments. None demonstrated any significant difference in their performance. Thus it seems reasonable to conclude that no amount of normal abuse to visco fuse will affect its burn rate.

Conclusion

The results reported in this article are for one series of tests of one manufacturer's visco fuse. While it is likely that other manufacturers' products behave similarly, that has not been verified.

Regarding visco fuse, there appears to be:

- a small amount of variation in burn rate along a length of fuse (approximately ±7%).
- a very small amount of variation in burn rate as a function of temperature (approximately ±5% extrapolating over the range 0 to 100 °F).
- a moderate amount of variation as a function of fuse covering or gluing (perhaps an increase of approximately 50% for the portion tightly covered or glued).
- no burn rate effect from normal abuse.

Acknowledgments

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References

1) American Visco Fuse, 11984 N. Telegraph Road, Carleton, MI 48117.

2) F.P. Agterberg, *Geomathematics*, Elsvier, The Netherlands, 1974.

3) A.A. Shidlovskiy, *Principles of Pyrotechnics*, Mashinostroyeniye Press, 1964, Reprinted by American Fireworks News.

4) J. Conkling, *Chemistry of Pyrotechnics*, Marcel Dekker, Inc., New York, 1985.

Notes

(a) Coefficient of Variation is a statistical measure of the degree of randomness in a series of repeated measurements. The coefficient of variation equals the standard deviation, expressed as a percent of the mean (average).

(b) Standard Error is a statistical measure of the uncertainty in the average value determined from a series of repeated measurements. The standard error equals the standard deviation divided by the square root of the number of measurements. One σ (sigma) is an indication that the true value has a 67% chance of falling within the limit of the error bars.

(c) There is another mechanism that could have been operating to significantly increase the burn rate of visco fuse when covered. Had there been an indication that this was the source of the increases observed in this study, there could have been important safety ramifications. However, a proper discussion of this subject is beyond the scope of this paper and must be delayed for a future article, which is already in preparation.