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Explosive Limit of Armstrong's Mixture

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When investigating the cause of an accident, it was necessary to learn something about the lower explosive limit with regard to phosphorus content in Armstrong's Mixture. A short literature search did not produce the needed information; thus a brief laboratory study was undertaken. Because the results of the study may be useful regarding safety and because they may be intrinsically interesting, this short article was prepared.

Armstrong's Mixture is both a very sensitive and very explosive pyrotechnic composition, potentially making it extremely dangerous.[1–3] Its practical use is limited to manufacturers of toy caps, although from time to time hobbyist experimenters are reckless enough to experiment with it. Davis[4] reports the formula for Armstrong's Mixture as given in Table 1. However, hobbyist experimenters often do not include the lesser two ingredients. There is little hope of mixing the ingredients in the dry state without their exploding, and dangerous reactions may occur even in the wet state.[3]

Table 1. Formula for Armstrong's Mixture.

Ingredient	Percent by Weight
Potassium chlorate	67
Phosphorus (red)	27
Sulfur	3
Calcium carbonate	3

In this study, to duplicate conditions of the accident, mixtures containing only potassium chlorate and red phosphorus were examined. Mixtures, containing from 2 to 30% red phosphorus, were prepared wet, using an additional 40% water. One-gram quantities of the mixes (dry weight of ingredients) were applied wet over the tips of electric matches in sample holders, see Figures 1 and 2. For each composition, three test samples were prepared. After drying for two days, the test samples were placed between two free-field blast gauges, one at a distance of one foot and the other at two feet, see Figure 3. Upon activating the electric match, the explosive output (as a blast wave) was recorded digitally for later analysis.

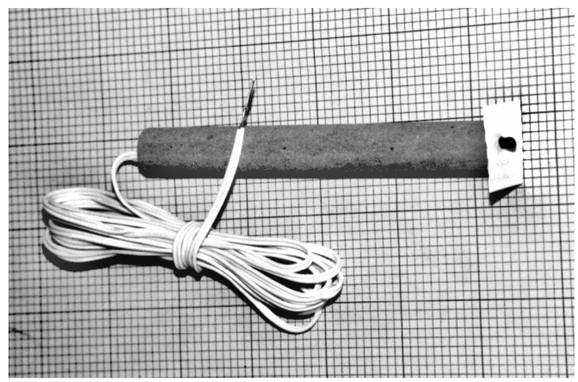

Figure 1. Test sample holder, made using a 5/16-inch ID paper tube with an electric match glued in place and protruding through a square of heavy filter paper.

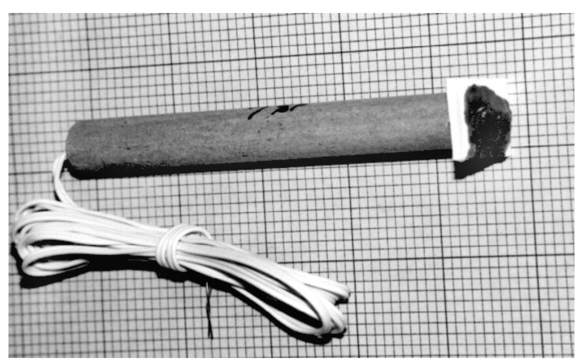

Figure 2. Test sample holder with a 1-gram sample applied over the electric match tip.

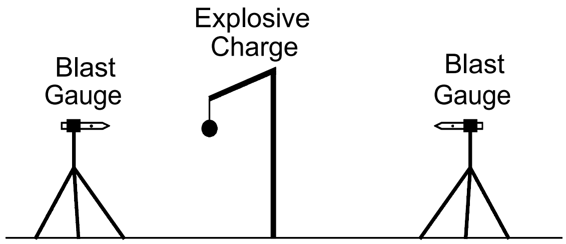

Figure 3. Drawing illustrating the set-up of blast gauges to measure the explosive output of the test samples (not to scale).

One method of reporting explosive output is in terms of TNT equivalent under specific conditions. For example, in these measurements, the maximum output for a sample was found to produce a TNT equivalent of 27%. For this sample, the explosive output (air blast wave) of 1 gram was found to be equivalent to that expected to be produced by 0.27 gram of TNT. The average results from the series of test mixtures are graphed in Figure 4 and demonstrated in Figure 5.

Note that in the case of 10 and 20% red phosphorus test mixtures, nearly one inch of the end of the support tube was blown off by just one gram (0.04 ounce) of material. For an unconfined pyrotechnic in such a small quantity this is impressive. (Considering the extreme sensitivity of these mixtures, this is just plain scary.) Note also that even small percentages of red phosphorus produce explosive results and would certainly be disproportionately more explosive in larger amounts.

Acknowledgments

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References

1) R. R. Rollins, "Potassium Chlorate/Red Phosphorus Mixtures", *Proc. of 7th Symposium on Explosives and Pyrotechnics*, Franklin Institute (1971).

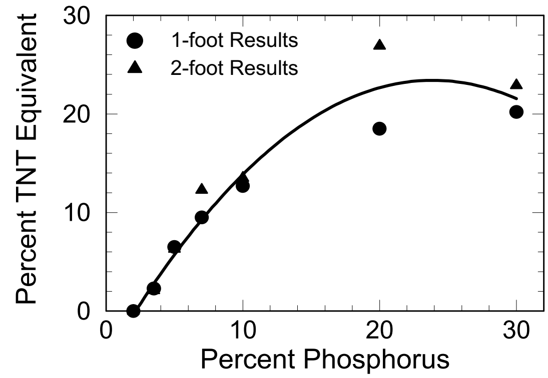

Figure 4. A graph of the TNT equivalent as a function of red phosphorus content. Air blasts were measured at 1 and 2 feet from 1 gram, unconfined test samples.

2) D. Haarmann, "Tell the Wiz, Armstrong's Mixture", *American Fireworks News*, No. 54 (1986) p 4.

3) D. Haarmann, "Tell the Wiz, Armstrong's Mixture", *American Fireworks News*, No. 51 (1985) p 3.

4) T. L. Davis, *The Chemistry of Powder and Explosives*, Angriff Press (1941) p 105.

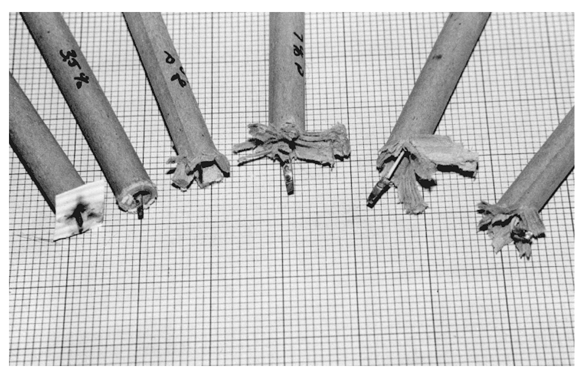

Figure 5. Representative examples of damage to the test sample holders for 2, 3.5, 5, 7, 10, and 20% red phosphorus mixtures, shown from left to right.

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Aerial Shell Drift Effects: (A) The Effect of Long Mortars

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(B) The Effect of Capsule-Shaped Shells

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ABSTRACT

Aerial shell drift is defined as the difference between the ballistically predicted trajectory of a shell and its actual trajectory. It had been speculated that longer length mortars and capsule-shaped shells might experience significantly different drift than normal length mortars and spherical shells. While longer mortars propelled 6-inch (155-mm) aerial shells to greater heights, the average shell drift was unaffected. Further, it was found that 6-inch (155-mm) capsule-shaped shells probably drifted slightly more than spherical shells.

Key Words: aerial shell drift, mortar length, shell shape.

Introduction

Knowing the initial conditions (mortar tilt and azimuth, wind speed and direction, and shell parameters), the flight path of aerial shells can be calculated using ballistics models.[1] While such calculations are fairly good at predicting the average path taken by a large number of identical shells, they are rather poor at predicting the actual path of an individual aerial shell. In large measure this is because of additional aerodynamic forces acting on the shells along their trajectory that are difficult or impossible to characterize prior to firing a shell. One example is the magnus force resulting from the shell tumbling along its path.[2] This force can not be determined without first knowing the rate and orientation of tumbling. Because this information is generally unknowable before a shell is fired, the resulting magnus force and drift cannot be predicted. (For a dud aerial shell, shell drift is defined as the difference between the ballistically predicted and actual points of fall of the aerial shell.)

Aerial shell drift was originally studied for to help determine the adequacy of spectator separation distances during fireworks displays. Based on initial tests, the average drift distance for dud spherical aerial shells was established to be approximately 32 feet per inch of shell size (0.38 m/mm).[2] If there are conditions that pro-