A Practical Performance Testing Protocol for Fireworks Mortar Tubes

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ABSTRACT

The author's development of an alternative design for a fireworks mortar coincided with the restructure of regulations concerning display fireworks in the State of Queensland, Australia. This new Code of Practice for the Display of Outdoor Fireworks has a requirement for manufacturers of equipment to develop performance-based tests that will prove the safety and suitability of plant and equipment used. The authorities proposed that a mortar tube was to be given a service life of five years. This article describes a protocol that has been successfully put into practice to test the new mortar tube. The protocol is called the Five Year Accelerated Test Program or "FYATP".

Keywords: mortar, plastic tube, service life, polyethylene

Introduction

A typical Australian fireworks mortar tube consists of an appropriate length of commercial polyethylene water pipe closed at one end with a wooden plug that is held in place by fasteners such as bolts, nails, screws or staples. This description also applies to most mortars available from the USA, except for one, which was considered to be superior to all others. This was a one piece, blow-molded mortar where the base is integral with the tube thus eliminating the weakness of a separate base plug and the variability of strength of the fasteners. The appeal of these mortars was considerably reduced by the high cost of transport to Australia, so the author decided to produce a mortar of a somewhat different design. The new mortar tube design has eliminated the traditional wooden plug and fasteners. Details of the associated construction, testing and results will be discussed in a future article. The replacement pipe closure system has eliminated the inherent plug and fastener weakness.

Having just designed a new mortar tube, the author felt that it would be appropriate to develop a testing protocol that would reveal how well the new mortar would survive five years of severe use. The test developed has been given the acronym "FYATP", which means the Five Year Accelerated Test Program.

The mortar tube was constructed with a nominal diameter bore of 2.5 inches (64 mm) and a nominal outside diameter of 75 mm (metric tube).

NFPA 1123, Code for Fireworks Display applies to the construction, handling and use of fireworks (and equipment) intended solely for outdoor fireworks displays and was used as a guide in the development of this mortar tube.[1]

Preliminary Assumptions

The aim of this program was to subject the mortar tube to a significant practical firing of an anticipated five years of severe usage where the internal pressures generated—using the largest lift charges and heaviest shells—would exceed normal operating conditions by generating excessive pressures. It was considered that using cylindrical shells and a heavier than normal lift charge of a faster burning propellant (4FA Black Powder), as compared to the normal slower 2FA that is customary to use with the smaller cylindrical shells in America, would exaggerate the extremes of operation.

In designing the test protocol, it was assumed that:

- A display company would discharge one aerial display shell per mortar per week per year, over the proposed five-year period.
- The majority of aerial display shells utilized in Australia are of the spherical variety.
- One in five shells could be a "peanut" or double-break shell.
- Cylindrical display shells could be used in place of spherical shells.
- Cylindrical display shells are heavier than spherical shells.
- Cylindrical display shells use a larger propellant (lift) charge than spherical shells.
- The nominal propellant charge for a 2.5-inch (64-mm) cylindrical shell is 1 ounce (28 grams) of 2FA Black Powder, which is consistent with American practice.
- The nominal propellant charge for a 2.5-inch (64-mm) spherical shell is 25 grams of what appears similar to 4FA Black Powder. This is consistent with measurements of the Black Powder used in these shells supplied to the Australian market from Asia.
- A shell can have a diameter that is 0.25 inch (6.4 mm) smaller than that of the nominal diameter of 2.5 inches (64 mm).
- A cylindrical shell is longer than a spherical shell (comets being an exception).

Test Conditions

The following test conditions were established based on the preliminary assumptions:

- The mortar tube will have a nominal bore of 2.5 inches (64 mm).
- A total of 260 shells will be fired to represent the assumed use over five years. All firings will be consecutive from the one mortar tube.
- All shells fired will be inert and of the cylindrical variety.
- The most common inert cylindrical shell fired will have the same nominal weight as a single spherical shell (without leader and lift charge), plus an additional 50%.
- Every fifth shell fired will be an inert cylindrical shell adjusted in weight to twice the weight of a nominal spherical shell.
- The lift charge will be based on a nominal propellant load of 1 ounce (28 grams) plus an additional 50% of 4FA Black Powder.
- The shell will be fired at ambient air temperature (in the shade), and the mortar tube will be allowed to cool to the same ambient temperature between firings. [These particular tests were carried out at approximately 20 °C, the full range varied from 16 to 25 °C over the course of this event. Ambient temperature readings were taken with an electronic thermometer, and an electronic surface probe was used for external temperature measurements on the mortar tube body.]
- The cylindrical shell will have a nominal diameter of 58 mm (2.3 inches).
- The cylindrical shell will have a length that is twice the nominal bore size for a total of 127 mm (5 inches).

Component details for a 2.5 inch (64 mm) inert test projectile:

- Type of projectile: cylindrical (of cardboard construction)
- Weight of standard test projectile: 80 grams nominal plus 50%, which equals 120 grams nominal, tolerance between 120 and 125 grams
- Weight of intermediate test projectile: 80 grams nominal plus 100%, which equals 160 grams nominal, tolerance between 160 to 165 grams
- Projectile diameter: 58 mm (2.3 inches) nominal
- Manufacturing diameter of projectile ranged between 58.4 and 58.9 mm
- Lift charge: 1 ounce (28 grams) of 4FA Black Powder plus 50%, which equals 43 grams nominal

When powder was dispensed with a volumetric scoop, powder weight variation was between 43.0 and 44.5 grams, but usually on the slightly heavier side of 43 grams.

Field Trial Requirements

The mortar is visually inspected before each test. Diameter measurements are taken at two points on the same plane 90 degrees apart at a specified height above the base of the tube. Visual observations and measurements are recorded, along with ambient air temperature and time of day of each firing.

The mortar assembly is installed in the test mount and prepared for trial. The mortar is held in a steel rack in a horizontal orientation and discharged in that position inside a steel-framed receptacle. Preparation of the lift charge involves inserting an electric match into a bag preloaded with 4FA black powder. The assembly is then placed at the bottom of the mortar. An inert projectile is slid down the mortar until it rests on top of the lift charge. The shell is then fired from the mortar electrically from a remote location.

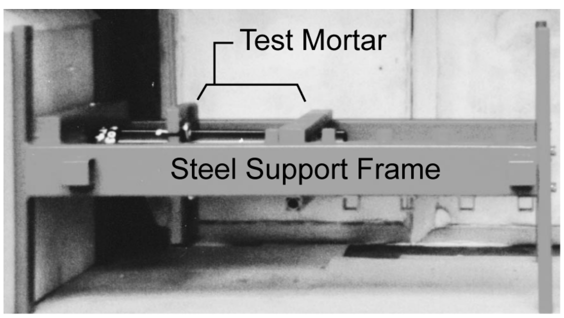

Figure 1. Photo of the horizontally-positioned mortar test assembly that is inside a steel test chamber.

The test sequence is cyclical, comprising four consecutive standard-weight cylindrical inert projectiles, followed by a fifth round that is a heavier-weight inert projectile. This firing sequence is repeated until the test sequence is either completed successfully or stopped due to failure of the mortar or for some other reason.

The mortar is visually inspected for signs of adverse effects and measured after each projectile has been fired. The diameters and observations are recorded.

Options for Physical and Environmental Assessment

After the test sequence is completed, a fully-cycled tube could be forwarded to a polymer laboratory with the request to perform a standard product test to the manufacturer's specification. An unused control tube could also be tested for comparison. Measurements taken on the control tube and the fully-cycled tube could be compared to see if there is any significant variation.

Appropriate tests for establishing some of the physical and environmental properties relevant to polyethylene pipe when used as a fireworks mortar tube could include measurements of the following:

- density
- tensile strength
- yield strength
- elongation
- elastic modulus
- flexural modulus
- environmental surface cracking
- oxidative induction time
- durometer hardness[2]

Measurement of the burst pressure could also be considered, but it should not be taken as an indication of the suitability of the pipe for use as a fireworks mortar. Burst pressure should only be considered as one more property to be used to see if there is any change after the accelerated five-year test.

Results

A 2.5-inch (64-mm) mortar developed by the author was tested using the Five Year Accelerated Test Program protocol outlined above. The grade of polyethylene used in the mortar was MDPE, type PE80B. The bore size complied with NFPA 1123. (Note however that HDPE type PE100 was not available in the size and SDR or PN number required.)

The rate of firing the 260 shots required for the test was approximately 20 shots per day, based on an 8 to 10 hour day. This rate of fire would change somewhat depending on the temperature of the day. The temperature of the tube was constantly measured to make sure it was the same as the ambient temperature of the air in the shade. However, as an indication only, this may have been from 15 to 45 minutes between firings, or 2 to 3 shots per hour. It took about three weeks of continuous activity to complete the test.

The mortar tube diameter was measured at the height where test mortars burst when shells were deliberately exploded inside them. The starting size of the unused tube was measured at two places that were located 90º from each other but in the same plane: Position 1 diameter was 75.65 mm and Position 2 diameter was 75.29 mm at 21 °C. At the conclusion of the set of tests, the measurements were: Position 1 diameter was 75.72 mm and Position 2 diameter was 75.45 mm at 21 °C.

Observations and Conclusions

The acceptance criteria for the test were no failures, no visual deformation, and no significant change in mortar tube diameter measurements over the entire test.

The condition of the mortar tube after the complete Five Year Accelerated Test Program was exceptionally good. The bore was scuffed as a result of the inert projectiles passing along it, plus there was abrasion from the hot propellant gases and particulates. Externally it was a bit marked from handling. Overall, however, it was extremely sound and looked as though it could survive several more complete FYATP sequences. There was no significant change in the diameter of the mortar from when the tube was first measured to the end of the test.

The test was completely successful and has shown the benefit of having a formal test procedure to assess the performance of a fireworks mortar. Tests of this nature can usefully indicate whether or not a mortar can be expected to be suitable for use over a specified period, in this case five years. The author considers that trying to establish an experimentally verified value for the maximum safe service life of a polyethylene pipe component of a mortar would be an enormous task. Given the resources and time to expand on the work done to date would be of benefit to all concerned and help answer the question: "What is the safe service life of a polyethylene mortar tube for the varieties and sizes available, taking into account or eliminating the inherent weakness of the traditional wooden plug closure and varying strengths of their associated fasteners?"

One limitation of the test protocol is that is does not address the effects of the age of the material.

It is recognized that further testing under different conditions would be of additional benefit but was beyond the scope of the current work. Such testing could include thermal cycling, UV exposure and examining the effects of the age of the material.

References

1) *NFPA 1123 Code for Fireworks Display*, National Fire Protection Association, 1995.

2) Saechtling, *International Plastics Handbook*, 2nd ed., Hanser, 1987, p 429. Durometer Hardness, extract: "The Shore A and D Hardness tests are emperical methods for semi rigid and elastomeric plastics. They are based on the specialized "Durometer" apparatus with a calibrated spring for applying force to a conically shaped indentor. For the A hardness series the indentor ends with a flat cross sectional cut, while for D it is more sharply pointed."