An earlier version appeared in *Pyrotechnics Guild International Bulletin*, No. 54 (1986).

HDPE Mortars for Electrically Fired Displays

K. L. Kosanke

When firing by hand, the problems of steel mortars can easily be over-looked. However, even for relatively small electrically fired displays, steel mortars and the usual alternatives (paper and PVC mortars) have limitations that are difficult to cope with.

Steel mortars are heavy; when several hundred may be needed for a show, their weight can easily exceed 5000 pounds. This may necessitate the use of a large truck and must certainly be seen as undesirable by the crew that will need to handle them several times. Service life is long, but high initial cost (about $1/pound) is another problem. Finally, even though steel mortars are quite strong, there is the possibility that a shell detonation may cause the production of dangerous mortar debris.

Paper mortars are lighter (about 1/3 the weight), cheaper (about 1/4 the cost) and produce less dangerous debris than steel mortars. However, the service life of paper mortars is generally quite short; probably about ten firings on average. Spiral tubes soon tend to have inner wraps peeling up which can bind a shell. All paper mortars will delaminate inner wraps if the mortars are even slightly damp when fired. Even treated paper mortars can be ruined by a single exposure to rain.

PVC mortars weigh and cost about the same as paper mortars. They are water proof and thus have a service life longer than paper. However, because the strength is less than steel mortars, so is their service life. The real problem with PVC mortars results from the combination of their only modest strength and the mechanism of their typical failure. Often a flowerpot and certainly a shell detonation will result in their destruction. Because PVC is relatively brittle, mortars—over-stressed in this manner—fracture and fragment. In addition, the fragments will usually have sharp edges and be pointed. This high velocity debris has the potential to do significant damage to nearby mortars and people.

A plastic mortar that retains all the good characteristics of PVC (low weight, modest cost, long service life) and eliminates the fragmentation problem would be near ideal. What is needed is a plastic that is strong, inexpensive and ductile. For the mortars to have sufficient strength requires a tensile strength approximately equal to that of PVC. For the mortars to be inexpensive requires not only a low base material cost but also that large amounts of pipe with the proper characteristics are already being produced commercially. Ductility is important because it results in a stress failure mode that might be described as bursting rather than fragmenting. Figure 1 is a series of sketches comparing the failure of less ductile (brittle) and ductile plastic mortars. Although fragments are still possible with ductile materials, often none will be produced. Also if any fragments are produced, they will have been stretched thin and will thus meet with greater air resistance, and will be slowed to harmless velocities sooner. Finally, if the material is somewhat flexible, fragments will tend to bend rather than penetrate on impact.

There are a number of promising plastics worth considering, but the one with the best overall characteristics is high density polyethylene (HDPE). This is basically the same material used to make plastic milk bottles; however, it is significantly stronger and is normally black in color (as used by the pipe industry). Table 1 is a subjective comparison of characteristics of steel, paper, PVC and HDPE mortars. As can be seen HDPE has characteristics that make it highly suitable for use as mortars in electrically fired displays. HDPE pipe is available in 2, 3, 4, 5, and 6 inch ID

In Table 1 note that HDPE's strength is listed as greater than PVC. This was done even though the tensile strength of PVC is reported as exceeding HDPE. When I initially considered HDPE, I assumed I would need to have special extrusion dies made and produce the pipe myself. Commercially produced pipe had wall thicknesses and pressure ratings that seemed inadequate for use as mortars. However, during early tests to determine the necessary wall thicknesses, I was pleasantly surprised by the unexpectedly high apparent

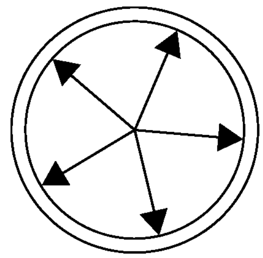
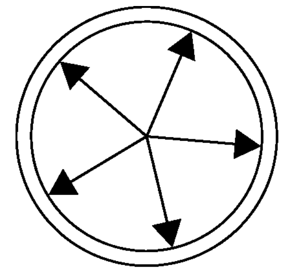
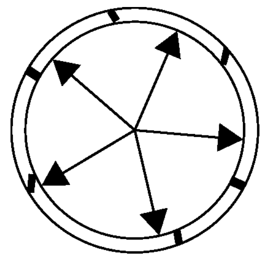
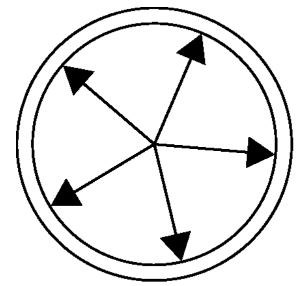
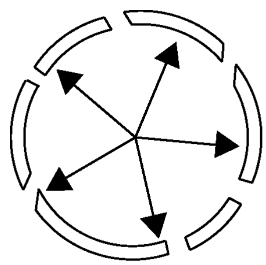
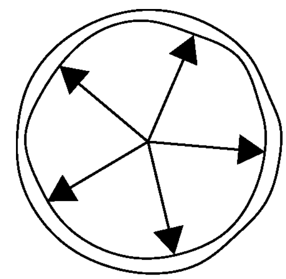
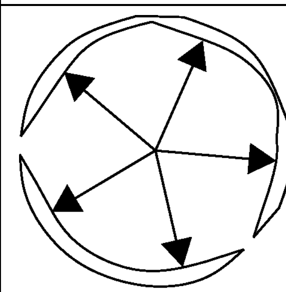
PVC — Less Ductile Mortar		HDPE — More Ductile Mortar	
Condition	Sketch (cross section)	Condition	Sketch (cross section)
High internal pressure.		High internal pressure.	
Rapid increase in pressure exceeds capacity. Pipe expands but fractures develop as elastic limit is soon exceeded.		Rapid increase in pressure exceeds capacity. Pipe expands and strength is reduced as diameter increases and wall thickness decreases.	
Many sharp high velocity fragments are generated.		Very high pressure continues. Elastic limit is exceeded and thin areas develop in mortar wall as it is stretched.	
		Very high pressure continues. Wall continues to be stretched thin until one or more tears develop venting pressure. Few if any fragments are produced.	

Figure 1. Comparison of failure modes of PVC and HDPE mortars.

strength of HDPE. Mortars made of HDPE pipe, with pressure ratings of only about ½ those for PVC mortars, consistently were capable of withstanding equal or greater stress than PVC mortars. The reason for this seems to be related to their differing failure modes, and the nature of tests performed to determine pressure ratings.

Figure 2 shows the approximate relationship between mortar strength and increases in mortar diameter due to internal pressure. The first portion of the graphs, when strengths are nearly constant, is characterized as elastic expansion of the mortars. Mortar strength falls slightly in this region because as it expands there is a slightly larger surface being exposed to the internal pressure. Mortars not stressed (stretched) further than their elastic limits (points EL in Figure 2) will regain their original diameter when the stress (pressure) is removed. Also they will not have suffered any permanent loss of strength. For PVC mortars the elastic limit is reached quite soon, and fracturing and fragmentation occur when the elastic limit is exceeded. This results in the strength of the mortar falling essentially instantly to zero. For HDPE mortars, the elastic flexing region is larger than for PVC. Also, when the elastic limit is exceeded, the mortar does not fracture, rather there is a flow (inelastic stretching) of the material. However, unlike the elastic flexing region, now the mortar will no longer return to its original diameter if the stress is removed, and there will be a permanent reduction in its strength. The loss in strength is the result of the pipe walls stretching permanently thinner. In this region of irreversible stretching the strength of the mortar falls more rapidly, but not instantly as it did for the PVC mortar. Finally, after continued stretching, the mortar tears open and its strength falls to zero.

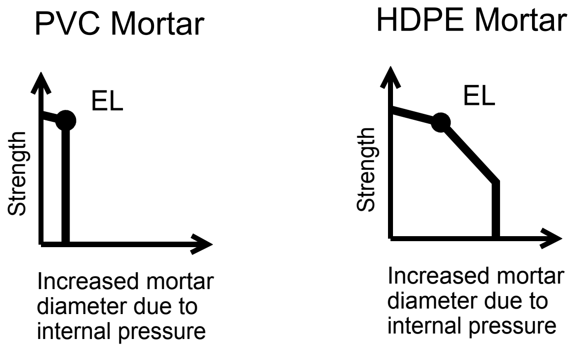


Figure 2. Approximate relationship between mortar strength and increases in mortar diameter due to internal pressure

Pressure ratings for plastic pipe are a fraction (usually ½ to ¼) the maximum pressure they can withstand for very long lengths of time when heated to their maximum operating temperatures. If the pipe material is elastic and deforms somewhat easily (desirable properties of mortars and mortar fragments), it may not stand up to pressure well over long periods of time. This is because as pressure is applied the pipe slowly expands a little; this causes the wall to stretch slightly thinner and exposes slightly more surface area to the pressure (i.e. the effective strength of the pipe is reduced). If the pressure is maintained, the pipe stretches further and weakens more. The process may continue until the pipe bursts. This does not mean that the pipe will not be able to successfully withstand a very short (fraction of a second) exposure to pressures many times greater than would burst the same pipe if sustained for many hundreds of hours. In comparison, a pipe that is more brittle, essentially unyielding under the effect of pressure, might withstand considerably higher pressures, until it fails catastrophically by shattering.

In a mortar, high lift pressures are sustained for only a small fraction of a second and are not uniform along the length of the mortar (i.e., they are high only below the shell being propelled). This sudden and non-uniform application of pressure may be considerably more stressful for a more brittle material like PVC than for one that is more ductile like HDPE. At any rate, this appears to be the case in practice, HDPE mortars (with rated pressures only ½ those of PVC) demonstrate equivalent or even superior strength in comparison with PVC mortars.

Table 2 summarizes the initial tests that were performed on HDPE mortars. As a result of these initial tests, it seems clear that HDPE mortars have both sufficient strength and service life to be used successfully as mortars for electrically fired shows. In addition, their failure mode strongly suggests they represent considerably less hazard to people and adjacent mortars that do PVC mortars. Accordingly, we have decided to replace 100% of our paper mortars (about 800) with ones made of HDPE.

Note that because HDPE mortars are quite resilient, it is possible to plug the mortars with wooden plugs stapled in place. Pre-drilling or screwing is not necessary as is the case with PVC mortars.

Table 1. Comparison of Characteristics of Steel, Paper, PVC and HDPE Mortars

Mortar Type	Weight	Cost	Strength	Number of Fragments If Over-stressed	Danger of Fragments
Steel	High	High	High	Few	High
Paper	Low	Modest	Low	Few	Low
PVC	Low	Modest	Low	Many	Moderate
HDPE	Low	Modest	Moderate	Few	Low

Table 2. Summary of Initial Tests with HDPE Mortars.

Test	Results
Destructive test: Salute in a short mortar at about 90 °F.	Mortar was turned completely inside out and several tears occurred at the end of the mortar where the salute was positioned. However, it appeared that no fragments left the mortar and the split ends of the mortars were thinned by stretching so that they were relatively flexible. Also, although the mortar was unsupported and above ground, it came to rest only three feet from its starting position.
Destructive test: Salute exploded in a short mortar cooled to about 15 °F.	The mortar was turned completely inside out and a small number of pieces were torn from it. However, the pieces were all stretched quite thin resulting in their being relatively flexible and having large surface areas in comparison to their weight. It seemed likely that a person, if struck by a piece, might receive an abrasion but a serious puncture wound seemed unlikely. Also it was difficult to imagine that adjacent mortars could have been damaged by mortar fragments.
Rapid fire test: Five 4” canister shells with normal lift plus five 50% over-lifted were fired from the same mortar in approximately 5 minutes. The final shell flowerpotted.	The mortar successfully withstood the test even though the temperature of the outside of the mortar — measured after the test — rose to over 150 °F.
Rapid fire test: Five 4” canister shells 100% over-lifted were fired in 3 minutes. The fifth shell flowerpotted.	The mortar successfully withstood the test.
Strength test: One 4” shell 200% over-lifted was fired from one of the above mortars.	The mortar successfully withstood the test.
Strength test: One 6” spherical shell with normal lift and one 6” canister shell 50% over-lifted were fired.	The mortar successfully withstood the test.
Durability test: Ten additional normally lifted 4” canister shells fired from each of mortars used in the rapid fire tests.	Inspection of inner mortar surfaces revealed a moderate build-up of Black Powder combustion products. After mortars were washed, inspection of inner mortar wall surface revealed essentially no deterioration.
Final 4” test: Ten Additional 4” canister shells, each 200% over-lifted, were fired in 6 minutes from a mortar cooled to 30 °F.	The mortar successfully withstood the test. (Note, the mortar had previously been used to successfully fire 20 shells.) There were no visible signs of mortar deterioration.

In conclusion we (Kosanke Services, Inc.) offer to share the experience we have gained with HDPE mortars with anyone wishing further information (phone 970–245–0692). This includes an offer to supply a limited number of test mortars for evaluation and a list of specifications and sources for HDPE pipe with the proper characteristics.