An earlier version appeared in *Fireworks Business*, No. 251, 2004.

The Effect on Mortars of Explosions within Them

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An earlier article[1] that appeared a little over a year ago discussed one type of mortar bursting explosion. The article described a process whereby a sufficiently powerful explosion occurring internally near the muzzle of a high density polyethylene (HDPE) mortar would not only burst the top of the mortar, but could also burst the plugged end of the mortar, frequently leaving the middle section of the mortar fully intact. Since publishing that article, readers posed two questions: 1) do the conclusions of the earlier article apply equally to explosions occurring near the plugged end of mortars; and 2) do the conclusions of the earlier article apply equally to mortars made of other materials. The simple answers to the two questions are no and yes, respectively. However, before addressing these two questions, the current article will very briefly summarize the observations made in the earlier article.

Figure 1 is a photograph of one mortar tested previously with a firework salute exploding after being positioned within the mortar near its muzzle. Clearly, both ends of the mortar have suffered severe damage, with the middle section essentially unaffected. As was explained in the earlier article, the bursting of the top of the mortar was caused directly by the explosion of the salute. Whereas the explosion of the plugged end of the mortar was the result of the blast pressure wave from the explosion traveling down the length of the mortar, reflecting off the mortar plug, and thus nearly doubling the strength of the blast pressure wave such as to also burst the bottom of the mortar. (Readers wishing a more complete discussion with supporting data should consult reference 1.)

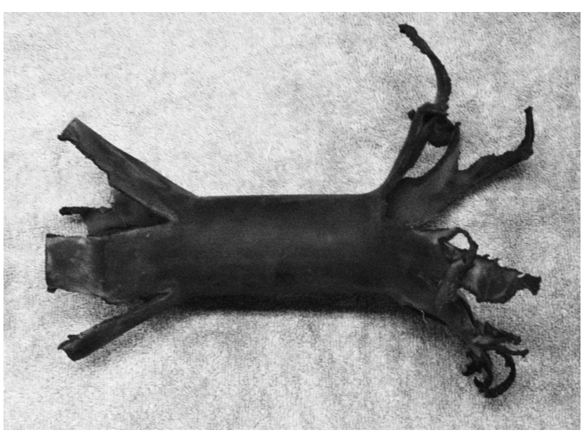

Figure 1. A photograph of a HDPE mortar following the explosion of a salute near its muzzle end (to the right).

Answer to Question 1

When a pressure wave travels along the inside of a pipe of constant dimension, it will diminish somewhat in magnitude as it progresses along the pipe. Over a distance of pipe equal to the length of a mortar the degree of reduction is only modest and for the purpose of this discussion can mostly be ignored. However, when a pressure wave travels along the inside of a pipe where there is a sudden change in the diameter of the pipe, there is an effect that cannot be ignored. Although it is blast waves that are of interest, perhaps the effect can most easily be explained in terms of simple sound waves.

When there is a sudden change in pipe diameter, this corresponds to a change in the pipe's acoustic impedance. A decrease in pipe diameter corresponds to an increase in acoustic impedance; whereas an increase in pipe diameter corresponds to a decrease in acoustic impedance. In both cases, large changes in diameter correspond to large changes in impedance. When a pressure wave reaches a sudden change in acoustic impedance, a reflected pressure wave will develop and will travel back upon the incident wave. The greater the acoustic impedance change, the greater (i.e., stronger) is the magnitude of the reflected pressure wave. When the change is from relatively low to relatively high acoustic impedance (i.e., from relatively large diameter to relatively small diameter), the reflected wave will be in-phase with the incident wave, causing reinforcement in the pressure wave at that point. To the contrary, when the change is from relatively high to relatively low impedance (i.e., from relatively small diameter to relatively large diameter), the reflected wave will instead be out-of-phase with the incident wave, thus resulting in a diminution of the pressure wave at that point.

In the case of a firework mortar, when a pressure wave from an explosion near the top of the mortar travels down and reaches the plug in the bottom of the mortar, this is a very great decrease in diameter (effectively to zero), corresponding to a very great increase in acoustic impedance. The result is an in-phase reflection (i.e., a reinforcement or strengthening) of the incident pressure wave at that point. As was demonstrated in the earlier article for a blast wave,[1] this can be sufficient to cause the bottom of a mortar to burst when a reasonably powerful explosion occurs in the top of the mortar, and yet can leave the middle of the mortar fully intact (see Figure 1).

In the case of a firework mortar, when a pressure wave from an explosion near the bottom of the mortar travels up and reaches the muzzle of the mortar, this is a very great increase in diameter (effectively to infinity), corresponding to a decrease in acoustic impedance. The result is an out-of-phase reflection (i.e., a diminution or weakening) of the incident pressure wave at that point. Because of the reduction of the pressure wave at the muzzle of the mortar, there is a reduced likelihood of bursting the top of the mortar. There is a chance that a sufficiently powerful explosion in the lower portion of a mortar could destroy the entire mortar (especially if the explosion occurs up a little way from the bottom of the mortar). However, there is no chance of bursting the top of the mortar if the middle of the mortar is to be left intact. To demonstrate this for blast waves, two tests were performed.

In the first test, using a mortar made with the same type of 2-inch (50-mm) high density polyethylene (HDPE) pipe as was used in Figure 1, a powerful firework salute was exploded in the bottom of a mortar. The salute contained approximately 2 ounces of a high quality flash powder. The result of the explosion is shown in Figure 2. In this case more than 60% of the length of the mortar was destroyed, leaving only approximately 5 inches (125 mm) of the muzzle end of the mortar intact. In the second test, again using the same type of 2-inch (50-mm) HDPE pipe, a 5 ounce (140 g) charge of a commercial high explosive was exploded in the bottom of a mortar. The result of this explosion is shown in Figure 3. In this case more than 80% of the length of the mortar was destroyed, leaving only approximately 2 inches (50 mm) of the muzzle end of the mortar fully intact.

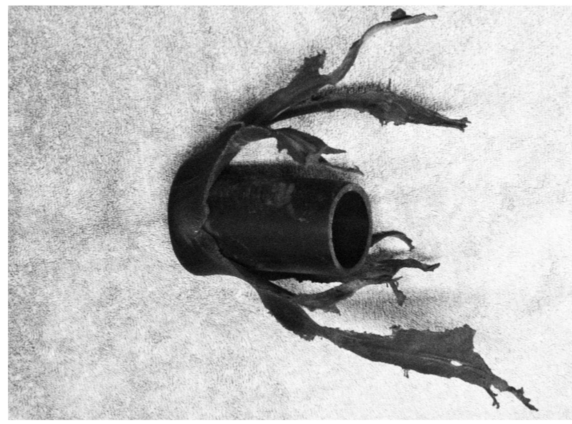

Figure 2. A photograph of a HDPE mortar following the explosion of a powerful salute at its bottom (to the left).

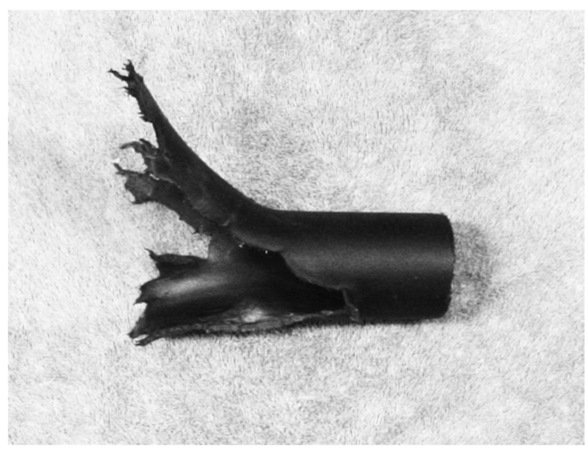

Figure 3. A photograph of a HDPE mortar following the explosion of a very powerful charge of commercial high explosive at its bottom (to the left).

Accordingly the answer to the first question is no, the conclusions of the earlier article do not apply equally to explosions occurring near the plugged end of mortars. As the result of explosions occurring in the lower regions of mortars, there is no chance of bursting the top of the mortar when the middle portion of the mortar has been left intact.

Answer to Question 2

The same physical principles that are at work within the test HDPE mortars apply to all other mortar materials as well. It is the basic design of the mortar, a tube with only one plugged end that causes this effect. As partial confirmation, note that in a recent series of tests of solid 3-inch (75-mm) cylindrical comets with a disturbing tendency to explode upon firing while still inside their mortars, nine paper mortars received this same type of double ended damage. See Figure 4 for examples of this type of mortar damage, with the mortars from left to right in the photograph suffering increasingly violent explosions.

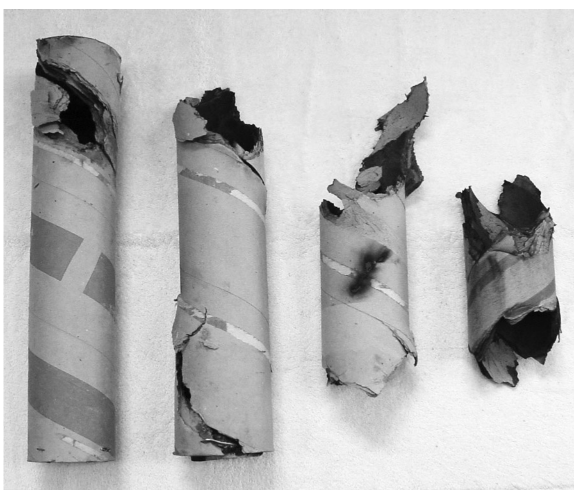

Figure 4. A photograph of a series of paper mortars following internal explosions occurring near their muzzle end.

It is true, however, that the strength of the mortar material does have a significant effect on the power of the explosion needed to produce the damage. Because of the relatively greater strength of steel mortars, many fairly powerful explosions occurring within them produce no visible damage to those mortars. Over the years the authors have observed several steel mortars having burst as the result of an explosion occurring within them. The authors do not recall one that suffered the same type damage as documented in Figure 1. However, the reason is not that steel mortars are not capable of bursting at both ends from explosions near their muzzle ends. In part the reason is that many of those mortar explosions were caused by salutes (or salute containing shells). Salutes that explode within mortars upon firing, almost universally do so when they are still relatively near the bottom of the mortar. Accordingly, these explosive events, while powerful enough to seriously damage (or totally destroy) the mortar, cannot produce double ended mortar damage, as was explained above. Another part of the reason seems to be related to the fact that malfunctioning star shells typically explode near the muzzle of their firing mortars. While occasionally these so called star-shell-detonations are powerful enough to burst the top of their mortar, rarely (if ever) are they powerful enough to also burst the bottom of their mortar, considering that the mortar bottom is substantially strengthened as a result of being solidly welded to a steel plug.

Accordingly, the answer to the second questions is yes, single explosions that burst both ends of the mortars while leaving the middle portions of the mortar intact, are not a direct result of the type of material used to make the mortar.

Acknowledgments

The authors are grateful to M. Podlesak (Defense Science and Technology Organization, Australia) for commenting on an earlier version of this article.

References

1) K. L. Kosanke and L. T. Weinman, "The Effect of Reflected Blast Waves in HDPE Mortars", *Fireworks Business*, No. 234, 2003; also in *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 7 (2003 and 2004)*, Journal of Pyrotechnics, 2006.