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Dynamics of Flash Tube Seals in 30-mm Ammunition

by Stephen L. Howard

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14. ABSTRACT
Certain 30-mm ammunition use a flash tube to augment the primer and to provide an ignition source for the propellant. The flash tube must provide abundant hot gases/particles and pressurize the propellant bed sufficiently so that the initial burn rate of the propellant is high enough to propel the projectile to the muzzle within the few milliseconds that constitute the action time of the cannon. Rupture of the seal at differing rupture pressures was shown to affect the initial pressure in the chamber enclosing the propellant bed, as well as the amount of burning particles released into the bed.

15. SUBJECT TERMS
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1. Introduction

Various 30-mm ammunition use a flash tube (figures 1 and 2) to augment the ignition stimulus of the primer and to provide an ignition source for the propellant bed in each round. The flash tube must be fast acting, provide abundant hot gases/particles, and increase the pressure in the propellant bed sufficiently so that the initial burn rate of the propellant in the bed is high enough to propel the projectile to the muzzle within the few milliseconds that constitute the action time of the cannon.

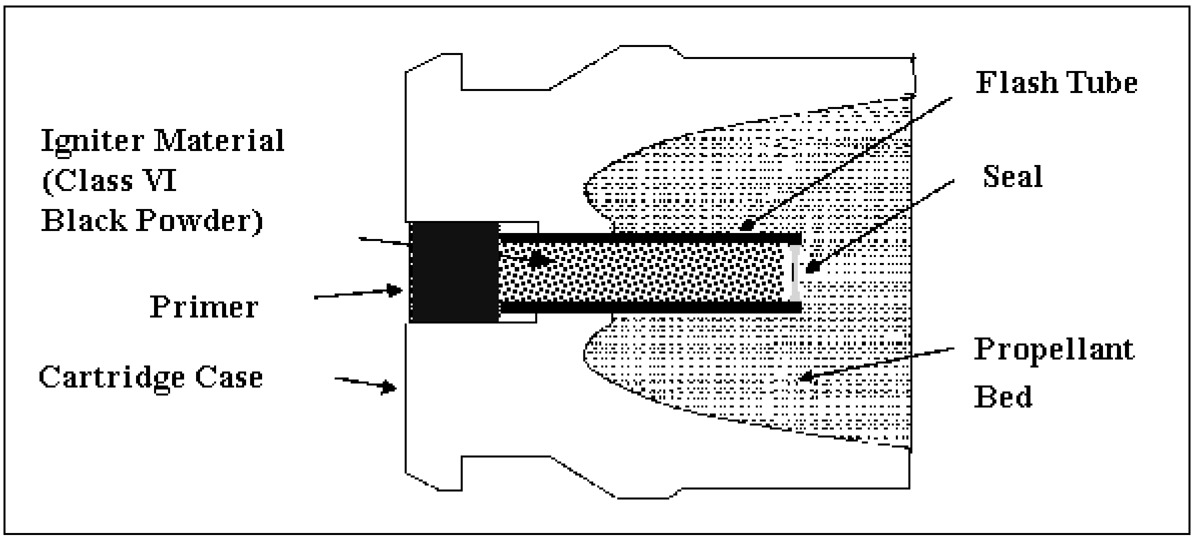

Figure 1. Schematic of breech end of a 30-mm round.

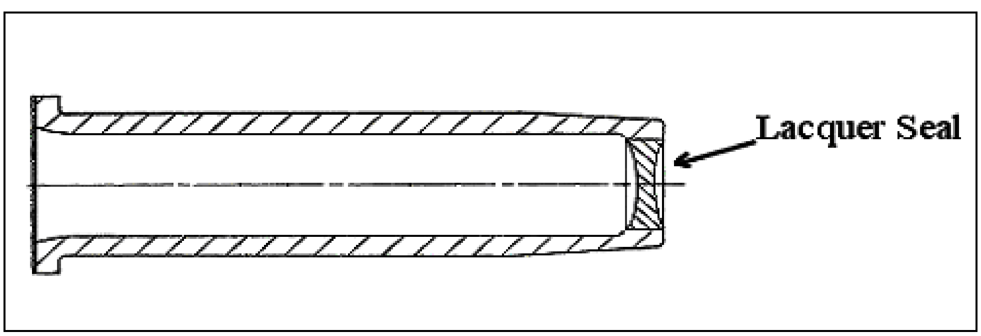

Figure 2. Schematic of flash tube used in tests.

The lacquer seal (*1*) on the output end of the flash tube is thought by some to do more than just keep the black powder in the flash tube. It should be sufficiently strong so that the primer output remains in the flash tube until the black powder is ignited and combustion products from the black powder have built up enough pressure and hot-particle density. When it does rupture, the pressure released, with the accompanying gas flow, should be sufficiently high to increase the pressure in the propellant bed so that the initial burning rate of the propellant is high enough to complete the ballistic cycle in the time required. A previous study (*2*) of the rupture pressure of the flash tube lacquer seal at up to rupture pressures of 78 MPa indicated that significant gas generation would be achieved before the flash tube vented into the main propellant bed. Gas flow at these pressures is expected to play a significant role in the ignition of the main propellant charge and rapid functioning of the round. However, that study only examined the flash tube venting into open air. This study also examines the use of the flash tube in an inert propellant bed to simulate actual functioning of the flash tube.

2. Experimental

The experiments were conducted on two test fixtures at the U.S. Army Research Laboratory (ARL) at Aberdeen Proving Ground, MD, USA. Figure 3 shows a simplified schematic of a fixture to test the dynamic rupture pressure of a flash tube lacquer seal as experienced by the flash tube. The flash tube was filled with 350-mg Class VI black powder (*3, 4*) and held in the fixture. An electric match provided the ignition stimulus and was placed behind the black powder in a void volume that was approximately the same as that of the conventional primer. The pressure was monitored with a Kistler 211B1 pressure transducer behind the electric match. The pressure-time history was recorded on a Nicolet Integra 20 digital oscilloscope. The rupture event was also monitored with a Phantom IV high-speed camera.

A second fixture simulated the inside of an M788, M789, or M799 round. This simulator was filled with inert propellant. The flash tube was held in a truncated casing (an actual casing was truncated to form a stub base with the proper interior geometry of the round) of an M789 round. The black powder in the flash tube was ignited by an electric match, and the pressure was monitored. Pressure in the propellant bed region was measured near the projectile location and near the breech. Figure 4 shows a simplified schematic of this fixture.

3. Results and Discussion

A previous study (*2*) determined the strain-related physical properties of the nitrocellulose (NC) lacquer seal. However, these results only described the physical behavior of the lacquer seal itself. Effects such as the solid black powder pushing up against the seal or possible weakening

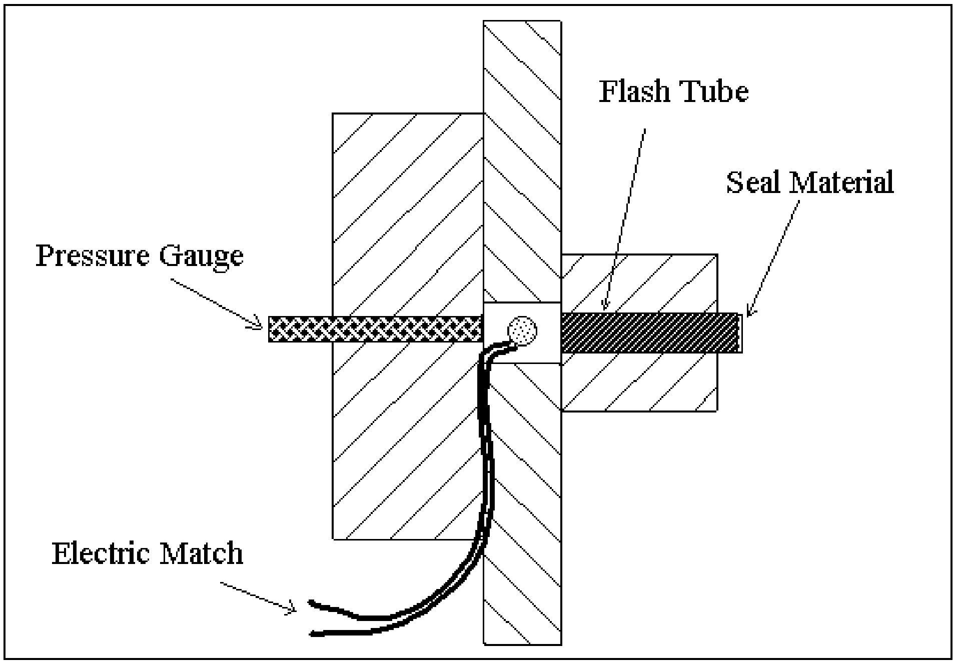

Figure 3. Simplified schematic of open air fixture to obtain the dynamic rupture pressure of a flash tube seal.

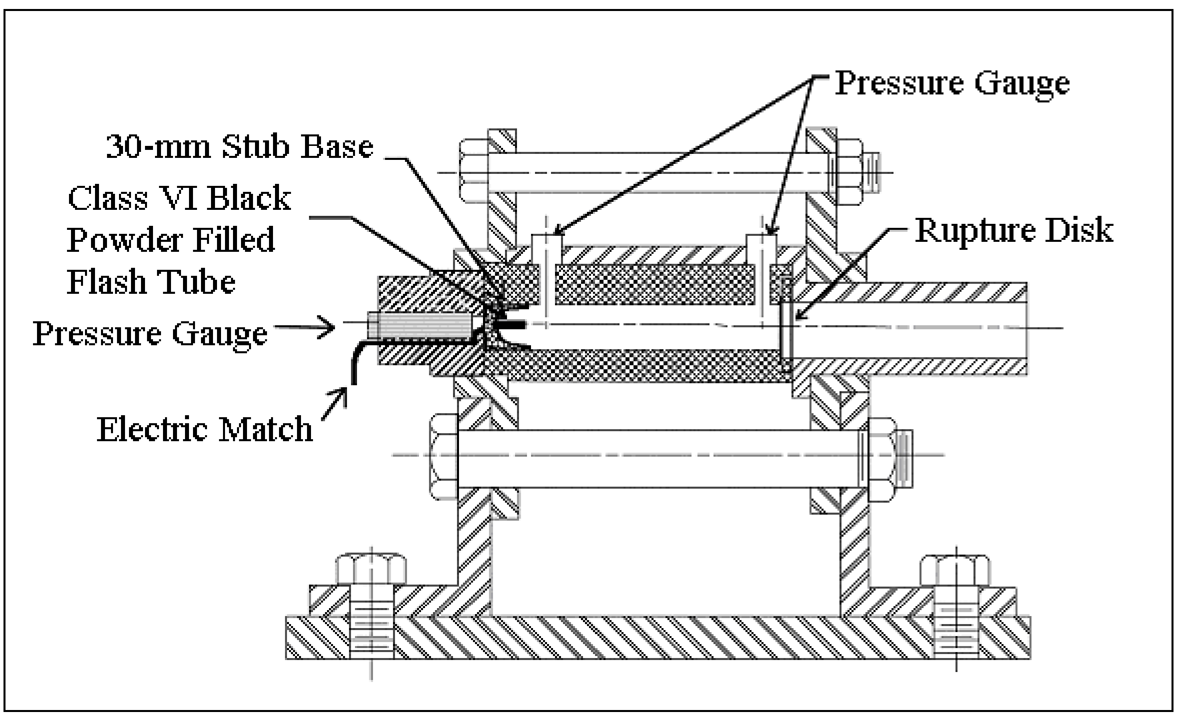

Figure 4. Simplified schematic of fixture to simulate the early-phase burning in 30-mm ammunition.

of the seal due to the temperature of the flame, etc., were carefully removed. In the current study, all the effects of a flash tube in typical operation were examined because the flash tube itself was filled with the correct loading of the proper grade of black powder.

Figure 5 shows the pressure-time history produced by the ignition of 350 mg of Class VI black powder in a properly functioning flash tube that vents into open air (see also figure 3). The pressure-time history of a standard NC seal (*1*) indicated that maximum pressure was reached at ~2 ms from black powder ignition. Rupture and essentially complete venting occurred by 4 ms. The maximum pressure reached was nearly 41 MPa.

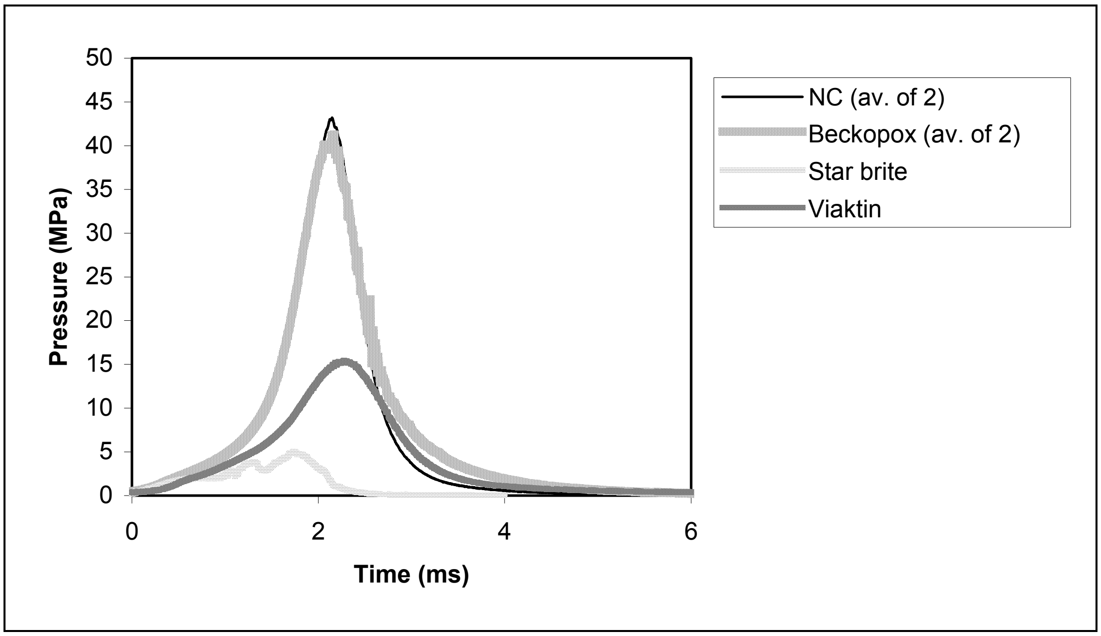

Figure 5. Pressure-time histories of interior of flash tube using selected seal materials.

Other coating materials were tried as possible NC replacements. It was hoped that candidates that were more environmentally friendly (also known as "green") would be found. The candidate materials were selected so as to have reduced (or totally eliminated) volatile organic compounds (VOC) in their composition or use (*5*). They were also selected so as to not contain any U.S. Environmental Protection Agency (EPA) Title I, Section 112 hazardous air pollutants (HAP) (*6*). With these restrictions in mind, the search was narrowed to materials that were aqueous, ultraviolet (UV)-activated, or thermal cured. Of the materials tested, those in figure 5 showed interest for demonstrating important aspects of expressed physical properties in the selection of a seal material for a properly functioning flash tube.

Pressure-time histories of the rupture of a seal fabricated from three of these materials are depicted in figure 5. Beckopox (Solutia, St. Louis, MO), a heat-cure material, most closely matched the NC lacquer. Other materials such as Viaktin (Solutia, St. Louis, MO) and Star brite (Star brite, Ft. Lauderdale, FL) showed dramatically different behavior in this application. The rupture pressures from these last two materials were much lower than that of the NC seal. The rupture pressure of the Star brite seal was especially low. This degraded behavior was deemed sufficient to simulate damaged NC seals. A damaged seal (cracked or missing, for example) would likely produce a lower maximum pressure and possibly lose a portion of the black powder into the propellant bed before ignition.

The results from the Viaktin and Star brite suggest that not all of the black powder was consumed. Indeed, the high-speed video showed burning particles ejecting from the Beckopox and NC seals only (see figure 6). After each test, the table on which the fixture was attached was swept for unburnt particles. Such particles were found only for the tests with Viaktin and Star brite seals (see figures 7 and 8). Some of the particles that were recovered were essentially the same size as the original black powder. Other particles were reduced in size as if crushing or other hydrodynamic particle reduction processes had occurred. It may be that during the early-stage ignition of the flash tube that some portion of the black powder was forced out of the flash tube prior to its ignition. Such particles of black powder would not contribute to rapid ignition of the propellant bed.

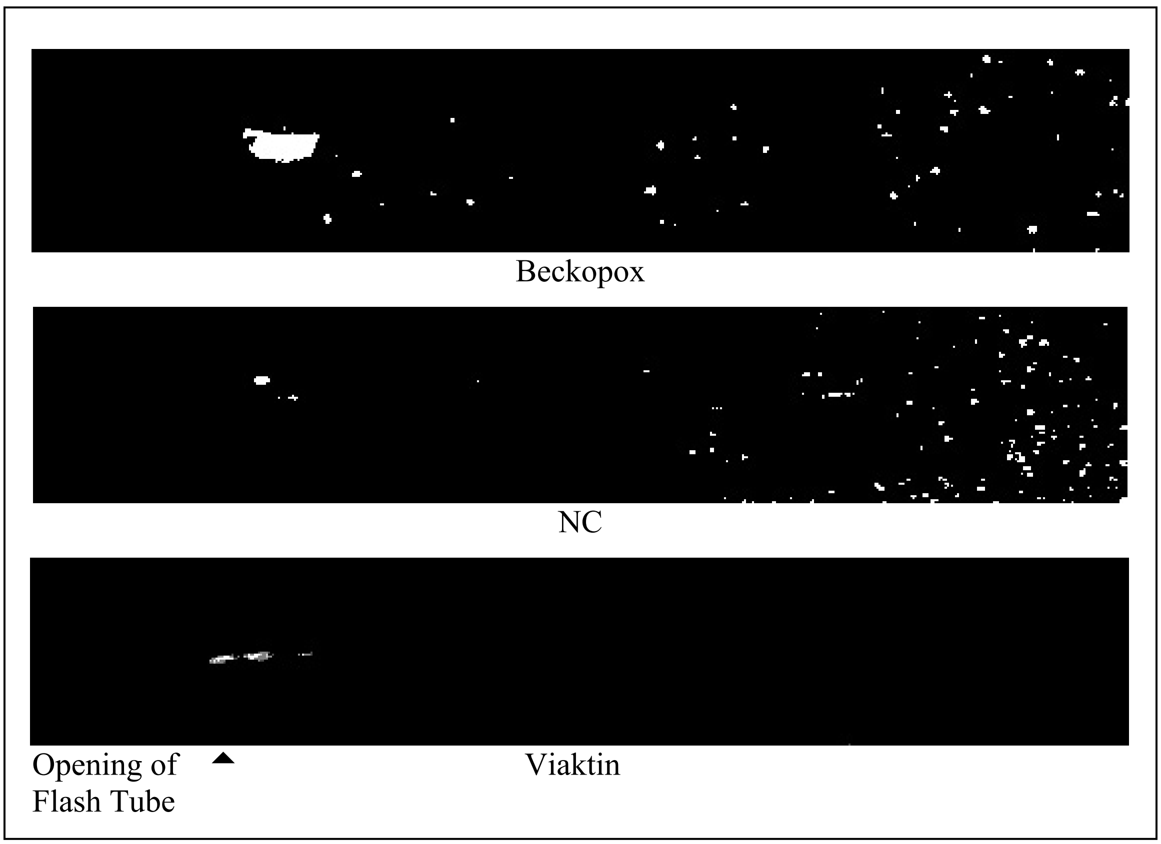

Figure 6. Frames from high-speed video after seal rupture into open air.

Figure 7. Photograph of original black powder particles.

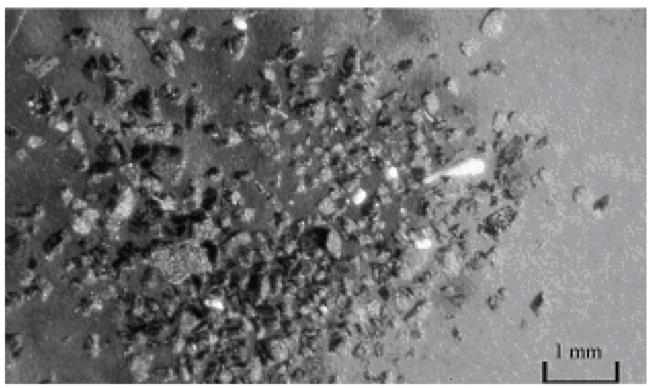

Figure 8. Photograph of recovered black powder particles
from test with Viaktin.

The simulator fixture in figure 4 was used to identify some of the conditions that would exist in the propellant bed during and after the functioning of the flash tube. The propellant bed in the following tests was filled with an inert propellant grain used earlier in 25-mm simulator tests (*7*). The first test was with a standard NC seal. Figure 9 shows the pressure-time history. The maximum pressure in the flash tube was ~42 MPa prior to rupture at near 1.7 ms. The breech pressure began to rise steeply at 2.2 ms to ~2 MPa by 2.8 ms, and the forward pressure rose more slowly to the same pressure by ~4 ms. The pressure then decreased, as is typical with heat loss from the gases to the inert grains after the propellant (black powder in this case) has burned out. The soot from the black powder penetrated into the inert propellant bed at ~60% of the bed length. The maximum bed pressure is similar to pressures observed in some Air Force tests with GAU-8 extract propellant (used in GAU-8/A ammunition at the time) and a WECOM flash tube (similar in construction and in black powder loading to the flash tube used in this study) at comparable temperature (*8*).

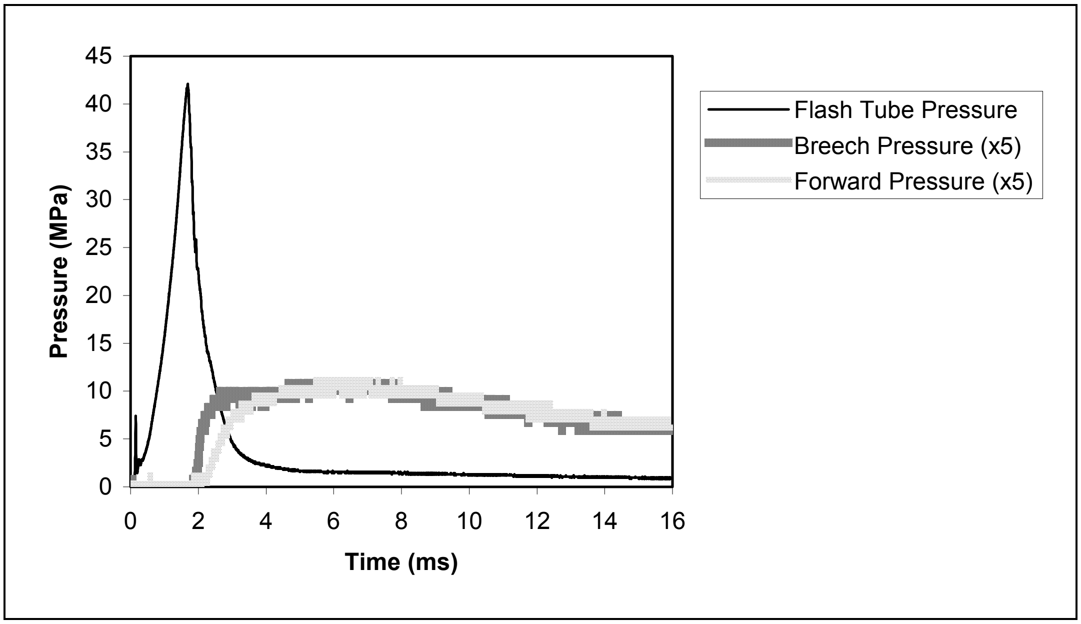

Figure 9. Pressure-time history of rupture of a good NC seal in the 30-mm simulator.

The test simulation of a damaged seal used a flash tube with a Star brite seal. The ignition of the flash tube produced the pressure-time history in figure 10. The pressure in the flash tube reached a maximum pressure of 2.5 MPa in 1.5 ms, but did not begin to fully vent until ~3 ms. At this point the pressure in the propellant bed began rising and continued rising for ~4 ms until it reached a maximum pressure of ~0.02 MPa that held steady for at least 15 ms. Such pressure behavior could indicate that black powder particles left the flash tube without burning and entered the propellant bed prior to combusting. After the particles were dispersed to some extent in the bed they burned more slowly and released gases at a sustained level during the time window observed. The soot from the black powder penetrated ~47% of the propellant bed. There is no way to tell how much of the soot was deposited during the initial release when the seal ruptured or from the prolonged burning of sprayed black powder particles after the flash tube vented.

Comparison of the pressure-time histories (see figures 9 and 10—please note the difference in scale and in the multiplicative coefficients in the legends) of a properly functioning flash tube seal and a damaged flash tube seal shows dramatic differences. The damaged seal produced more than an order of magnitude reduction in pressure in the flash tube and nearly a two-orders of magnitude reduction in pressure in the propellant bed. A side-by-side comparison of the two data sets using the same vertical scale shows more dramatically these differences (figure 11). These reductions in pressure and burning particles (see also figure 6) should produce degraded performance in the functioning of ammunition with a damaged seal.

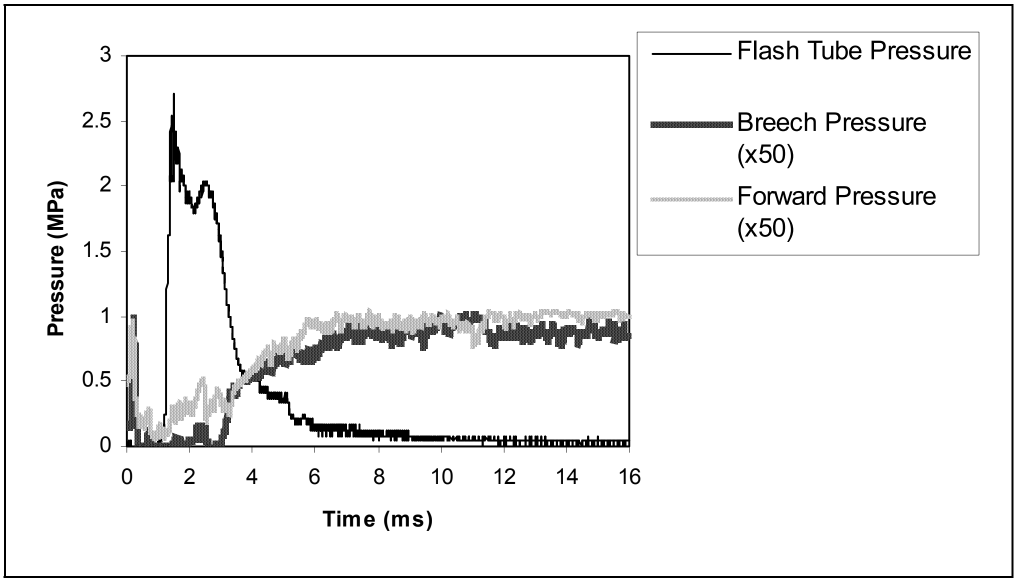

Figure 10. Pressure-time history of rupture of simulated damaged seal in the 30-mm simulator.

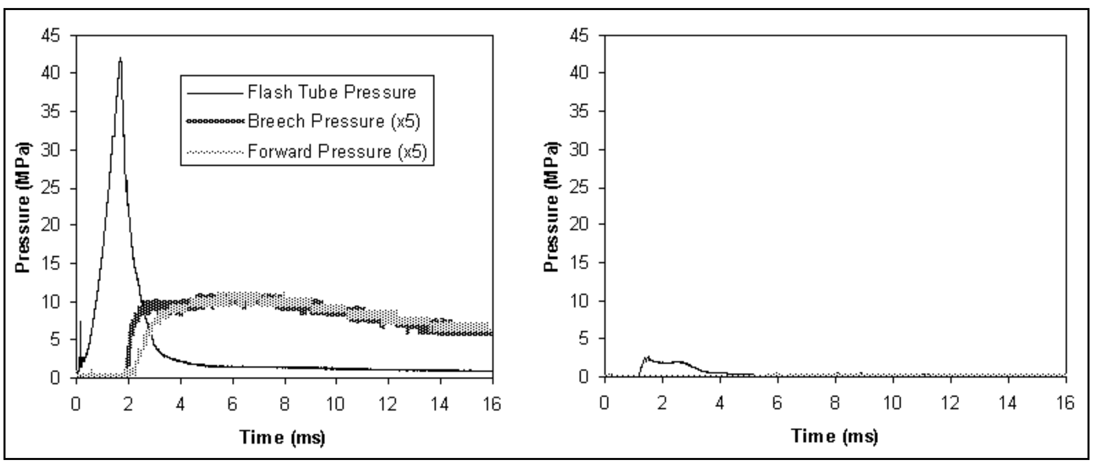

Figure 11. Side-by-side comparison of a good and a simulated damaged seal in the 30-mm simulator.

With the study of several candidates simultaneously, it was obvious that the physical properties of a replacement material for a particular grade of NC lacquer should be considered before the final selection. Even changing to a different NC lacquer in an effort to affect the strength, brittleness, thickness, etc., the new seal should be tested for physical properties so that the goal of improving the flash tube operation is achieved instead of actually degrading the performance.

4. Summary

The lacquer seal on a flash tube for 30-mm ammunition was shown to perform more functions than a simple environmental seal. Use of fixtures that vented the output from the flash tube into open air or into an inert propellant bed demonstrated that proper functioning of the seal could greatly affect the conditions present during the early-phase combustion of the propellant bed. With damaged or defective seals, both pressure in the propellant bed and burning particles vented from the flash tube decreased dramatically with the ability of the seal to hold pressure as the black powder was ignited.

If changes are to be made to the standard NC seal material, physical properties that affect the actual function of the flash tube and the operating of the ammunition should be measured and evaluated. Other physical properties such as performance at hot and cold temperatures (not undertaken in this study) should also be obtained and compared to the standard NC seal. This study showed that such properties, even though possibly not visible to the naked eye in an unused seal, could dramatically affect the operation of the flash tube and possibly degrade the performance of the affected ammunition.

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