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Development of PAX-3 Explosive for the Bunker Defeat Munition

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The U. S. Army Armaments Research, Development and Engineering Center's (ARDEC) Energetics and Warheads Division, with support from the Office of the Project Manager for Close Combat Systems (PM-CCS), is evaluating the high-blast explosive PAX-3 as a replacement for the current Aluminized Comp A3 explosive fill in the Bunker Defeat Munition (BDM). Warheads were press loaded using both the existing production equipment and procedures at ambient temperatures with no vacuum, and in a vacuum fixture at various temperatures, pressure dwells and vacuum levels to optimize the explosive density. Warheads were subjected to system level specification testing to determine performance capabilities in both optimal and operational environments. Targets included Earth and Timber Bunkers, Triple Brick Walls, Reinforced Concrete walls and steel plates. Warheads were also subjected to selected environmental conditions to assess system safety issues under extreme circumstances. In addition, PAX-3 is completing full explosives energetic qualification testing including long term aging studies, sensitivity testing, mechanical property evaluation, stability, compatibility, and performance. Extensive scale up and producibility studies have also been conducted on PAX-3. A variety of compositional mixtures were developed and tested to evaluate producability and fabrication issues, molding powder pressability, cost and performance.

INTRODUCTION

The Bunker Defeat Munitions system is a short range, man-portable, shoulder fired, infantry assault munition used to destroy fortified positions (earth and timber bunkers). It can be fired from the standing, kneeling, and prone positions. It is the single shot version of the U.S. Marine's Shoulder-launched Multipurpose Assault Weapon (SMAW). It uses the same High Explosive Dual Purpose (HEDP) warhead and has a disposable launch tube that provides half the carry weight while maintaining target performance.

The BDM was jointly developed by the U. S. Army Armament Research Development and Engineering Center, Picatinny, New Jersey, and Talley Defense Systems, Mesa, Arizona. The system weighs 15.7 pounds, is 32 inches in length, and includes a night sight mounting fixture (see figure 1). The system is also capable of defeating very lightly skinned armored vehicles and generating various size holes in masonry walls, and is being used by Coalition Forces in Operations Iraqi and Enduring Freedom.

Figure 1. Bunker Defeat Munition warhead and launcher.

The Office of the Project Manager for Close Combat Systems (PM-CCS) has been interested in developing modernization programs to address new capabilities and system deficiencies [1]. In an effort to increase warhead performance and reduce IM sensitivity, the U. S. Army Armaments Research, Development and Engineering Center's (ARDEC) Energetics and Warheads Division, with support from PM-CCS, has been evaluating the new and improved high-blast explosive PAX-3 to replace the current Aluminized Comp A3 explosive fill in BDM.

PAX-3 EXPLOSIVE DEVELOPMENT

PAX-3 is a pressable high-blast explosive developed at Picatinny Arsenal, ARDEC. Warheads used against earthen type targets or structures generally use the blast effect created by the explosive as the defeat mechanism. These types of explosives have additives to increase blast effect late in the detonation process and are usually referred to as high-blast explosives [2]. PAX-3 is an HMX based explosive that contains approximately sixty-four percent HMX and twenty percent aluminum added to increase blast effects. The current explosive fill for BDM is Aluminized Comp A3 and contains approximately sixty-four percent of RDX and 30 percent aluminum. PAX-3 cylinder test and detonation product equations of state have been previously published [3, 4]

The BDM warhead consists of an aluminum outer case filled with approximately 2.5 pounds of explosive. The explosive is press loaded into the warhead case. A fuze cavity is machined in the rear of the warhead for receiving a multifunction fuze that is capable of discriminating between hard and soft targets. For this work, BDM warheads were press loaded with PAX-3 using both the existing production equipment and procedures at ambient temperatures with no vacuum, and using a vacuum fixture at various temperatures, pressure dwells and vacuum levels in order to optimize the explosive density.

Warheads were subjected to system level specification testing in accordance with MIL-STD-810E, 'Environmental Test Methods and Engineering Guidelines', to determine performance capabilities in both optimal and operational environments. Targets included Earth and Timber Bunkers, Triple Brick Walls, Reinforced Concrete walls and steel plates. Warheads were also subjected to extreme environmental thermal cycling and shock conditions to assess system safety issues under extreme circumstances.

In addition, PAX-3 is completing explosives energetic qualification testing including long term aging studies, sensitivity testing, mechanical property evaluation, stability, compatibility, and performance. Extensive scale up and producibility studies have also been conducted on PAX-3. A variety of compositional mixtures were developed and tested to evaluate producability and fabrication issues, molding powder pressability, cost and performance.

PAX-3 QUALIFICATION TESTING

PAX-3 was developed under the Army's Insensitive Munitions (IM) program in the early 1990's. In the mid-1990's, the high-blast capabilities of PAX-3 were demonstrated in the Penetration Augmented Munition (PAM). PAX-3 was loaded into the PAM Follow-Through-Charge and successfully tested against standard steel reinforced concrete Bridge Pier targets. In the late 1990's there was renewed interest in applications for high-blast warheads. PAX-3 was compared to several other high-blast explosives and tested against concrete, bunker and selected steel targets [2]. It has application as a main charge explosive where high-blast, high-energy output is required.

The composition of PAX-3 is 64% Class 5 HMX, 20% Aluminum, 9.6% Bis 2,2-dinitropropyl acetal formal (BDNPA/F), and 6.4% Cellulose acetate butyrate. It is a pressed, plastic bonded explosive, and its ingredients are readily available. Approximately 5,000 pounds of PAX-3 were successfully processed at the Hercules explosive plant formerly located in Mine Hill, New Jersey, at the in-house facilities of the Picatinny Arsenal's Energetics and Warhead Division, ARDEC, New Jersey and more recently at ATK-Thiokol, Corrine, Utah, using batch processing. The PAX-3 has been produced by contractors ranging in size from 5 to 25 pound batches. The explosive has been processed successfully using vertical mixing. The total processing time for PAX-3 of a typical 25 pound batch in a 5-gallon kettle is 4-1/2 hours.

The PAX-3 explosive is undergoing explosive qualification testing in accordance with established procedures as outlined in the Army Qualification Board Matrix which follows NAVSEA 8020.5C, the Navy qualification outline. Qualification consists of a series of safety and performance tests to evaluate explosive sensitivity, compatibility and performance. PAX-3 is the high-blast version of PAX-2A. PAX-2A has been used as a replacement for Comp A5 in items such as the 40mm M915 grenade. It is an insensitive alternative to Comp A5 and outperforms it in both Bullet Impact as well as Sympathetic Detonation. PAX-2A is qualified by both the Army and the Navy.

Table 1 contains sensitivity and performance data for PAX-3 along with data for selected pressed explosives currently fielded. Aluminized Comp A3 is mainly used in high-blast applications such as the defeat of structures, whereas LX-14 is used primarily for metal pushing applications, as in the collapse of a shaped charge liner or the fragmentation of a warhead case. PAX-3 provides both metal pushing capabilities and high-blast output.

Table 1: Sensitivity and Performance Data

	PAX-3	PAX-2A	Al Comp A3	LX-14
Impact (50%) cm	39.5	23	80.4	26
LSGT	129	137	121	199
VTS Ml Pass Criteria is <2.0mL	0.18	0.034		0.21
Detonation Velocity m/s	8070	8464	8199	8680

PAX-3 was evaluated for Thermal Stability and passed the test requirements with a burn reaction. Exudation and Irreversible growth tests were also performed on PAX-3 following MIL-STD-1751A, Method 1161 and Method 1162. Although there is no formal pass/fail criterion for exudation testing, no significant exudation was noted for the PAX-3. As for irreversible growth, the average percent volume change of PAX-3 was 0.3489%, which was found to be negligible. There was no change in appearance, no cracking, or no discoloration of any kind observed for PAX-3. While irreversible growth testing does not have a pass/fail criterion, there were no problems noted for PAX-3. The critical diameter was also determined for PAX-3 in accordance with MIL-STD-1751A, Method 1091. This number is essential because it defines the failure threshold diameter for the propagation of detonation. The critical diameter for PAX-3 was found to be between 0.074-

inches and 0.085-inches and therefore can be used in smaller system applications as well.

The Variable Confinement Cook-Off Test (VCCT) is a simulation of an explosive in a munition under high temperature conditions like fire, and this test is used to predict the level of reaction under confined conditions. The reaction level is defined as a burn, pressure rupture, deflagration, explosion, partial detonation, or full detonation. The VCCT test apparatus consists of an aluminum thermal sleeve, steel confinement sleeves of increasing wall thickness, endplates, heating bands, and thermocouples which monitor and control the temperature of the assembly. Two PAX-3 pellets were inserted into the aluminum sleeve, and in turn this assembly was inserted into a steel confinement sleeve. The heating band was wrapped around the steel assembly. The thermocouples were placed between the aluminum sleeve and confinement sleeve. The two endplates were sealed on both ends with four bolts. Slow cook-off testing was initiated with a two hour temperature soak time beginning at 230^{o}F. The temperature was increase at a rate of 6^{o}F/hr until a reaction occurred with the PAX-3 pellets at 375^{o}F. The T-15 confinement thermal sleeve produced a burn reaction, the T-30 and T-45 produced pressure ruptures, and the T-60, T-75, and T-120 produced explosions. Although a reaction less then an explosion is desirable, PAX-3 produced very good results at the low confinements, and it is felt that the borderline results from the higher confinements can be easily mitigated through the use of warhead design attributes like passive venting. Fast cook-off testing was also conducted, beginning at ambient temperature and ramping up as quickly as possible until a reaction occurred. For PAX-3, this took approximately eight minutes and occurred between 470^{o}F and 485^{o}F. The T-15, T-30, T-45, T-60, T-75, T-90, and T-120 confirment sleeves all demonstrated simple burn reactions.

Aging of PAX-3 is also being conducted in accordance with NAVSEA 8020.5C. The study at 60^{o}C, 30% Relative Humidity is complete. Data has been collected and there has been no change in sensitivity of the PAX-3. The study at 50^{o}C, 30% Relative Humidity will conclude in June of this year. Up to this point, no changes in sensitivity have occurred.

WARHEAD PRESSING DEVELOPMENT

The current production fill for the BDM warhead is Al Comp A3, and is press loaded at ambient temperature with no vacuum. The as-pressed nominal explosive density is 1.79 gm/cc or about 95% of Theoretical Maximum Density (TMD). An explosive pressing study was conducted at Day and Zimmerman, Parsons, Kansas to develop procedures to press PAX-3 into the BDM warhead and optimize for explosive density. A minimum of 1.78 gm/cc (98.5% TMD) was established as the target density for PAX-3.

A variety of pressing parameters were evaluated including vacuum vs. no vacuum, ambient and elevated temperatures, multiple pressure dwells, single and multiple charge increments, and various pressures. In addition, both standard PAX-3 and optimized PAX-3 formulations were evaluated.

Warheads than were press loaded with the standard PAX-3 explosive using the current production process (ambient temperature, no vacuum) produced warheads with separations and internal voids. Separations of the explosive from the warhead case occurred mostly in the nose section, and small voids around the fuze cavity were noted. Some low density areas between the explosive charge increments were also observed. These areas were originally thought to be voids (based on x-ray analysis) but showed no discontinuities after sectioning of the charges. Figure 2 presents an x-ray of a low density area and a sectioned warhead. The nominal pressed density for these warheads was 97% TMD.

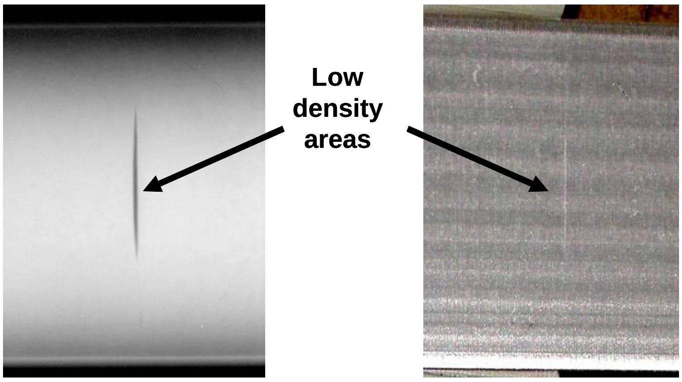

Figure 2. X-ray (on left) showing an apparent void and the cross section of warhead (on right) showing no discontinuity.

A vacuum press fixture was fabricated and warheads were press loaded at various temperatures, vacuum levels and compaction cycles. Both standard and optimized PAX-3 explosive was successfully pressed to the target density of 98.5%TMD. An x-ray evaluation showed no evidence of internal voids or separations. In addition, optimized PAX-3 was press loaded using the standard production equipment at ambient temperature and no vacuum to a density of 97.5% TMD and demonstrated no evidence of voids or separations.

DEVELOPMENTAL PERFORMANCE TESTING

PAX-3 loaded BDM warheads were tested against standard Al Comp A3 warheads to measure performance parameters against bunkers and enclosed spaces. Warheads were fired statically at earth and timber bunkers to evaluate differences in destructive capabilities. Warheads were detonated inside a standard ten-foot by ten-foot concrete enclosure to measure blast overpressures. Comparison photos presented in figure 3 show that PAX-3 produced increased damage over the standard Al Comp A3 loaded warheads against bunkers. In addition, pressure gages inside the enclosed concrete room registered readings that were approximately fifteen to twenty percent higher for the PAX-3 warheads, than for the Al Comp A3 warheads.

Figure 3. Bunkers tested with standard Al Comp A3 warheads (on left) verses PAX-3 tested bunkers (on right) showing more damage.

BDM WARHEAD SYSTEM LEVEL TESTING

Functional Evaluation Testing

As a risk reduction measure prior to full-up system performance testing, PAX-3 loaded warheads were subjected to extreme thermal conditioning and flight tested for proper fuze functionality against soft target impact. Five warheads each were temperature conditioned to -54 °C (-65 °F) and 71 °C (160 °F) and fired at the standard Lot Acceptance Test target. This target is a surrogate for the Earth and Timber Bunker and functions the warhead fuze in the delay mode required for bunker defeat.

The surrogate target is designed to initiate the delay fuze mode upon impact. After passing through the target, the warheads detonate at a prescribed distance downrange, assuring proper delay time. In the event that the fuze functions improperly, a steel backstop is placed behind the surrogate target. All Warheads functioned successfully between the Lot Acceptance Test target and backstop.

Figure 4. Surrogate target used to initiate BDM warheads in delay mode with steel back backstop.

System Performance Testing

PAX-3 loaded warheads were tested to evaluate the capability of the rounds against the required targets. Twenty rounds were fired in a performance test series to establish an operational baseline and to assess performance characteristics at ambient conditions. The targets included the standard Earth and Timber (E&T) Bunker, Triple Brick Wall, the 8-inch Double Reinforced Concrete Wall; and a hard target made up of Rolled Homogeneous Armor (RHA) plate. The testing was designed to verify proper system performance against intended targets.

The flight tests were conducted from a rigid, fixed stand with a strapped-down launcher. All twenty rounds were conditioned to ambient temperature (70 degrees F). Five each rounds were fired at the standard Earth and Timber Bunker at 150 meters range at 0 and 45 degrees obliquity. Two rounds were fired at the Triple Brick Wall at 50 meters and 0 degrees obliquity. Two rounds were fired at the Triple Brick Wall at a 50 meter range and 45 degrees obliquity. Four rounds were fired at the 8" Double Reinforced Concrete Wall at a 50 meter standoff and 0 degrees obliquity. The last two rounds were fired at a hard target (armor plate) at 50 meters and 0 degrees obliquity. All warheads functioned properly and testing was successfully completed without incident. All PAX-3 loaded warheads performed as expected against the tested targets.

System Safety Testing

Warheads were tested to assess performance at operational environments and to establish that the round does not become a hazard to the operator after exposure to extreme environmental conditions. The objective of the safety tests was to provide data to determine the existence and nature of actual and potential system hazards to personnel and equipment, the safety of the system after exposure to the extremes of anticipated manufacture-to-battlefield environmental conditions, and safety of the system for storage, transportation, handling (including training and non-firing operations), maintenance, firing, and disposal. Testing included Temperature Cycling, Thermal Shock, Transportation Vibration, 2.1-meter Drop, Loose Cargo Vibration, 1.5-meter Unpackaged Drop, and Flight Firings and the test sequence is presented in figure 5.

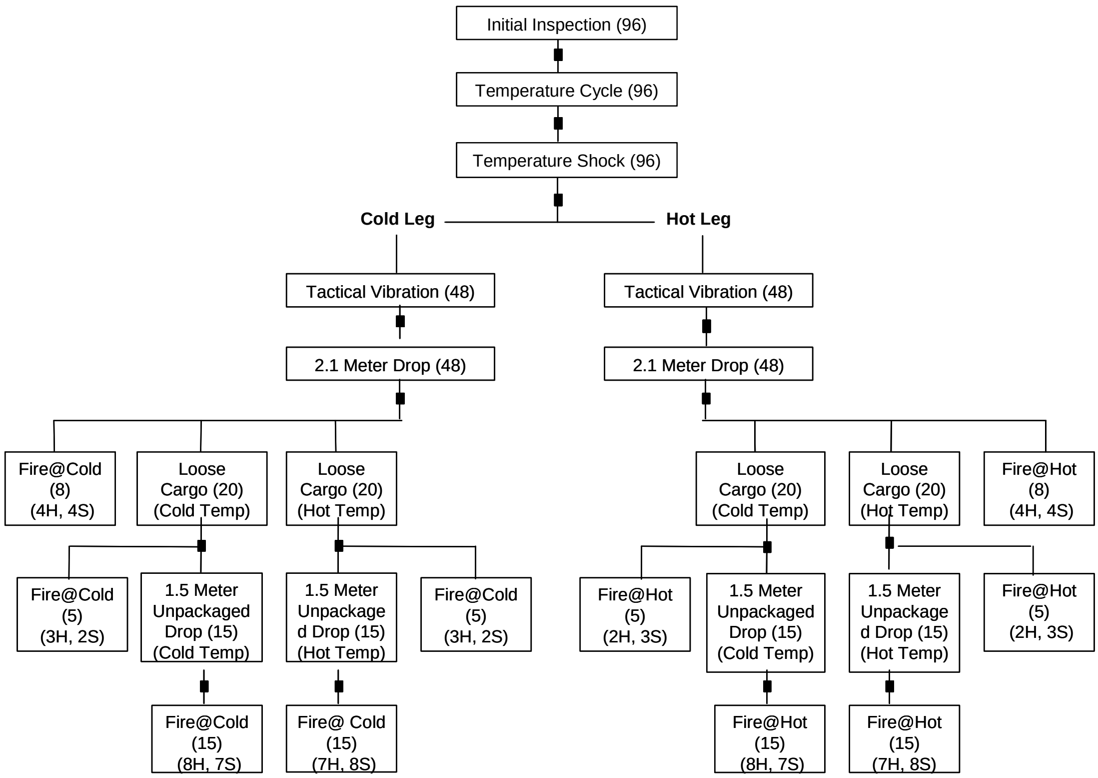

Figure 5. Testing sequence for the extreme environmental conditioning of PAX-3 loaded BDM warheads.

Temperature Cycling and Temperature Shock tests were completed without any major incidences. Tactical Vibration resulted in fuze misalignment in several warheads. Loose Cargo vibration testing resulted in minor damage to exterior components. The environmental conditioning test sequence was completed with no indication of safety problems with respect to the PAX-3 loaded warheads.

Flight tests were conducted on the environmentally conditioned warheads at both hot and cold temperature conditions. Test firings were conducted from a rigid, fixed stand with a strapped-down launcher. A surrogate soft target was used to evaluate warhead performance in delay mode, and a steel target plate was used to evaluate hard target function. Although there were firing issues with respect to the interaction between the rocket launcher and test stand at extreme cold temperatures, the flight tests were successfully completed with no indications of safety problems with respect to the PAX-3 warheads and their function on target impact.

CONCLUSIONS

BDM warheads were successfully loaded with the high-blast explosive PAX-3 and tested for performance against standard earth and timber bunkers, masonry walls and steel targets. They were also subjected to extreme environmental conditioning and tested for function and safety issues. The PAX-3 loaded warheads function properly with no detrimental effects. Warheads were also subjected to static and dynamic comparison testing to evaluate the performance against the current explosive fill. PAX-3 warheads were shown to produce more damage to earth and timber bunkers than the Al Comp A-3 filled warheads.

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