Performance Characterization of LEXFOAM from Hand-Held Systems

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ABSTRACT

LEXFOAM is an explosive foam developed from two non-explosive components to replace C-4 or TNT in humanitarian demining. This paper discusses a recent break through in packaging, the properties of newly developed LEXFOAM and improvement in delivery based on deficiencies noted in field testing. The Hand-held delivery system consists of two disposable aerosol cans. A large aerosol can contains 500 gm of the LEXFOAM stock solution and a small aerosol can contains 60 gm of blended liquid hydrocarbon propellants. LEXFOAM develops only after mixing the two components on-site in the stock solution aerosol can. The LEXFOAM becomes an explosive only after the foam is been dispersed. This paper describes and discusses the physical-chemical properties of LEXFOAM produced by hand-held systems and test results of their performance against a variety of unfuzed live mine targets. User interface, target mine types, effectiveness variation as a function of temperature, and potential applicability in humanitarian demining environments are discussed.

INTRODUCTION

People in more than 60 countries face a daily threat of being killed or maimed by millions of landmines remaining in the ground after the conclusion of hostilities. Mine clearance is a very slow, dangerous, and expensive. It is imperative to eliminate this global landmine crisis as soon as possible. In an effort to help mitigate this crisis, the U.S. Congress in 1995 directed the Department of Defense to initiate a research and development effort to optimize the speed and safety of demining. The mission is to develop new equipment and techniques for detecting, marking, and clearing landmines using off-the-shelf materials and technologies as much as possible. The Humanitarian Demining Team, Night Vision and Electronic Sensors Directorate (NVESD), Communications and Electronic Command (CECOM) executes this DoD program to develop and demonstrate technologies for humanitarian demining. Liquid Explosive Foam (LEXFOAM) is a successful neutralization technology developed under the R&D Program.

BACKGROUND

LEXFOAM, developed by Mining Resource Engineering Limited (MREL), is a nitromethane based explosive which forms as a foam once dispensed. The white self-supporting foam can adhere to walls. LEXFOAM is resistant to both mild rain and large temperature variations. The stock solution is a combination of nitromethane (NM), thickeners, emulsifiers and surfactants. The stock solution main component is NM and is classified as a flammable liquid, class 3. The stock solution is charged with an appropriate amount of liquid propane which is also a flammable liquid, then pressurized with nitrogen

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gas at 180 psi. LEXFOAM becomes an explosive only after it has been dispersed in foam form. The voids in the foam are believed to sensitize the nitromethane.

Backpack and Palletized LEXFOAM delivery systems were developed in 1995. Test results show LEXFOAM was 100% effective against tested surface and one inch buried AP and AT mines. The Backpack tank has a capacity of 31.7 lb. (14.4 kg) of LEXFOAM stock solution. The backpack delivery system, when loaded and ready to deploy, weighs 79 lb. (36 kg). The Bosnia-Herzegovina Mine Action Center (BHMAC) and the Cambodia Mine Action Center (CMAC) also evaluated the backpack delivery system. CMAC found that LEXFOAM is intended to minimize the need to uncover the mines, speed up the demolition process, add a high degree of versatility, and address the problem of attacking above ground mines. However, CMAC reported several problems with the system. It was too heavy for their deminers. The eight foot long LEXFOAM delivery trap was too long to maneuver in a one meter wide clearing lane. Nitrogen and propane gas tanks are not easily available in Cambodia. In addition, plenty of water is needed to clean the unit at the end of the day. To address these problems, Golden West Products International developed a disposable Hand-held LEXFOAM dispenser.

SYSTEM DESCRIPTION

The handheld system consists of 500 gm of LEXFOAM stock solution in a disposable aerosol can and a second, smaller container with 60 gm of the blend liquid hydrocarbon propellants (propane, n-butane and isobutane). In the field, the blended liquid hydrocarbon propellant would be injected into the LEXFOAM stock solution can before use. As with the backpack unit, LEXFOAM is produced only after the two components are mixed and dispensed from the aerosol can. When this mixture is exposed to the atmosphere, the liquid hydrocarbon propellant expands to a gas producing foam with a physical consistency of shaving cream. Only foam produces a highly effective explosive. The foam makes intimate contact with uneven and rounded surfaces, where the use of highly explosive blocks is inefficient. It also simplifies the attack of above ground and awkwardly placed mines. Mine neutralization occurs by spreading the LEXFOAM from an aerosol can on the mine, then remotely detonating it with an electric cap. The mine is neutralized by sympathetic detonation. Therefore, the LEXFOAM should be applied directly to the part of the mine containing the explosive fill.

MIXING PREPARATION

Each LEXFOAM kit contains two aerosol cans. The larger can (unit A) contains 500 gm of LEXFOAM stock solution. The smaller can (unit B) contains ~`60 gm of blended liquid hydrocarbons. Both units contain specially designed valves, but unit B has an adapter, which fits on the unit A valve. Before transferring the propellant from the unit B to the unit A, one should shake unit A well. Insert the unit B adapter into the unit A valve stem, press unit B against unit A for 15 seconds, then remove it from the unit A. Remove the trapped air from unit A by inverting it and applying the pressure on finger pad actuator for five seconds. Shake the unit A and repeat the transfer procedure of liquid hydrocarbons as described above except this time you apply downward pressure more than 30 seconds instead of 15 seconds. Continue the transfer procedure until all liquid hydrocarbons transferred are in unit A. Once the transfer is done, remove the unit B and set aside for disposal. Now the stock solution of nitromethane becomes LEXFOAM in the unit A.

EXPERIMENTAL INVESTIGATIONS

Mixing Various Amounts of Blend Hydrocarbons Propellant in LEXFOAM Stock Solution:

Several A and B units were placed outside for 30 minutes to reach equilibrium temperature with the air. The full unit B with a cover was weighed on the Triple-Beam balance with an accuracy of a 0.1gm. Testers transferred the propellant from unit B into unit A as described. After the transfer they weighed unit B with the cover. The difference between initial weight and final weight gave the amount of propellant transferred to unit A. Follow the identical procedure for the rest of the mixtures to make 20,30,40, 50, 60 and 96 gram propellant in the LEXFOAM stock solution cans.

Measurement LEXFOAM density at various amount of propellant in the LEXFOAM at different temperatures in the field:

LEXFOAM densities were measured using a classical method in the field at atmospheric temperatures in various seasons. 400-mL Pyrex beakers were used for weighing the foam using the Triple-Beam balance. Overflow was removed by running a straight edge of plastic sheet across the top of the beaker. Each LEXFOAM mixture was weighed three times. The volume of the beaker was measured by weighing a full beaker with water, assuming water density to be 1 g/cc. Once we knew the mass and the volume of the LEXFOAM we calculated the density of the LEXFOAM using a simple formula; Density =Mass/Volume = gm/cc. All the density data at different temperatures and various mixtures of the propellant in the LEXFOAM are tabulated in Table-1A to 1C.

Detonation Velocity Measurement:

Detonation velocity was measured in the field at environmental conditions with LEXFOAM in paper trays. Each paper tray was constructed from file folders, 2" wide, 2" high, 10" long and 0.001" thick. A special hole was punched in the center at one end of the paper tray for inserting an electric. The first wire was inserted 3" away in the center from the basting cap. Each of the other wires were inserted one inch away from the previous wire. The paper tray was placed on a three inch wide and 12 inch long witness plate as shown in Figure 1

Figure 1 Experimental set-up for measuring Detonation velocity of LEXFOAM in a paper tray at 88 ^{0}F

(left). Both ends of each wire were connected to an instrument. The LEXFOAM stock solutions were fully charged (57-59 g). Also, 40 g of the hydrocarbons were utilized for this investigation. The LEXFOAM was sprayed in the top of the paper tray and completely encased the break wires as shown in Figure1(middle). The LEXFOAM was then detonated from one end of the paper tray and the time that each wire was broken was measured. The detonation velocity was calculated from the timing of the wires breaking and the known distance between the wires. The detonation velocity of LEXFOAM for various amounts of propellant charged were measured and results tabulated in Table-2.

Critical Thickness Measurements of the fully charged LEXFOAM:

Six rectangular paper trays of various heights and widths, but with identical length were constructed from a file folder. Their dimensions were 2" High (H) x 4" Wide (W) x 6" Long (L), 1.5" H x 4" W x 6" L, 1" H x 4" W x 6" L, 1"H x 2" W x 6" L, 1" H x 1" W x 6" L, and 0.5" H x 1" W x 6" L. Each tray had a hole in the center for inserting a # 6 electric cap. Each tray was placed on a witness plate six feet apart from each other in a line. Fully charged LEXFOAM was used to fill each tray. The gently inserted electric cap from the hole and over flow of the excess LEXFOAM from each tray was removed using a straight edge of plastic sheet run across the top of it. The LEXFOAM was initiated simultaneously.

Confinement Investigations:

Both metallic and plastic tube types were used. The metallic tube had an inner diameter of 1.6 " and was 6" long while the plastic tube had a 1" inner diameter and was 4.65" long. One end of the each tube was covered with a 0.2-mm thick paper lid with a hole in the center. The lid was easy to open and close and was used to insert an electric cap. The tubes were placed vertically as shown in Figure 2 (left) keeping the lid at top on 6 x 6-inch witness plates. The tubes were filled with fully charged LEXFOAM and closed with the paper lids. The electric cap was inserted from the top in each tube through the paper lid. The foam in each tube was detonated in one-minute intervals with an electric cap. The results on the both witness plates were noted.

Stability Investigations:

Two experiments were conducted two using fully charged LEXFOAM containers with propellant. The LEXFOAM was sprayed directly on the soil in about a 3" radius circle using a full can of LEXFOAM and left over night. In the morning we noticed several cracks two to three mm thick. The electric cap was introduced into the foam and the LEXFOAM pushed together. The LEXFOAM was initiated remotely with the electric cap.

The second experiment was performed on a 6 x 6" witness plate. Fully charged LEXFOAM was sprayed on the witness plate as shown in Figure 3 (left) and left overnight. There were several cracks on the LEXFOAM, Figure 3 (middle), in the morning. The electric cap initiated the LEXFOAM remotely. The witness plate was bent upward in all four corners as shown in Figure 3 (right).

Mines Tested:

Fully charged hand-held LEXFOAM systems were used against AP and AT mines of various cases. Both AP and AT unfuzed mines were surface (flush) buried immediately before testing. AP mines were tested first. The LEXFOAM was spread on each mine from a distance of one foot. The LEXFOAM was sprayed in small and large precise patches depending on mine size. An electric cap was inserted in the LEXFOAM and initiated remotely. Initiating the electric cap neutralizes the mine by sympathetic detonation from the high order detonation of the LEXFOAM. The test results of the both AP and AT mines are tabulated in Table-3.

RESULTS and DISCUSSIONS

Density:

Temperature ^{0}F	54	54	55	57	57
Amount of Propellant in gm	20	30	40	50	59
Density of LEXFOAM g/cc	0.212	0.257	0.237	0.223	0.245

A

Temperature ^{0}F	72	72	72	70	68	72
Amount of Propellant in gm	24	31	40	49	59	96
Density of LEXFOAM g/cc	0.307	0.325	0.31	0.31	0.27	0.297

B

Temperature ^{0}F	46	55	72	82
Density of LEXFOAM g/cc	0.214	0.237	0.31	0.458

C

Table 1, Density of LEXFOAM by varying the amount propellant, A at 54-57 ^{0}F and B at 68-72 ^{0}F and C at various temperatures with 40 g propellant in each LEXFOAM solution.

Data from Table 1A and B reveals density remains nearly constant by varying the amount of blend hydrocarbons in the LEXFOAM solution. However the density differs slightly in both tables due to temperature variation, being less at lower temperatures. Table1C shows densities measured at various atmospheric temperatures, keeping the same amount of blend hydrocarbons in the LEXFOAM solution. LEXFOAM density varies with temperature as shown in Table 1C. From Table1C density varies 0.0037 g/cc per ^{0}F from 46 to 72 ^{0}F degrees, while variation in density per degree F from 72 to 82 ^{0}F is 0.015 g/cc. This value is four times higher than the density variation below 72 ^{0}F. Generally, densities are little affected by changes in temperature for solid and liquid explosives, but of the two, changes are higher in liquid explosives. The density of technical grade NM (CH3NO2) is 1.133 g/cc at 73 ^{0}F. LEXFOAM stock solution is nearly 90 % NM. The other 10 % is surfactant and fuzed silica powder. The liquefied blend hydrocarbons are gases under normal room temperature and pressure. In LEXFOAM stock solution the blend hydrocarbons are present as liquid and therefore are confined at a temperature above their boiling point as a result of the pressure in the LEXFOAM container. When the LEXFOAM solution is dispensed into the atmosphere, the propellants flash from a liquid to a gas. This action produces LEXFOAM. The general definition of density is mass/volume. In LEXFOAM, the volume is expanded due to escaping hydrocarbon gases. Therefore LEXFOAM density is nearly 75 % less than liquid NM. As the temperature increases, more hydrocarbons escape from the LEXFOAM as a result of decreasing volume and increasing density. LEXFOAM density is also affected by atmospheric or barometric pressure. At higher elevations where the atmosphere is thinner, LEXFOAM may have lower density. Below sea level the atmosphere is dense. As a result the LEXFOAM volume decreases and density increases. Density depends on several factors such as temperature, pressure and how hard one can apply pressure on the Finger Pad. However, we observed that density is independent of amount of hydrocarbons present in the LEXFOAM.

Detonation Velocity Measurement Results:

Amount of Propellant in gm	57	57	45
Detonation Velocity, m/s	3810	4233	3810

Table 2. Detonation velocity m/s and grams of propellant in LEXFOAM solution at 88 ^{0}F

The measured detonation velocity of LEXFOAM is tabulated in Table 2 at 88 ^{0}F. Generally, detonation velocity is defined as the rate at which a detonation wave propagates through an explosive charge. It depends mostly on the heat of the explosion. However, several other factors such as the chemical nature of the explosive, density, charge diameter, degree of confinement, external pressure and inert additives affect the detonation velocity. We found out that average measured detonation velocity is 3951 m/s or 3.951 km/s. The test equipment is limited to 100,000 Hz. We found that the distance between the break-wires was too short (2.54 cm or 1" apart) to accurately measure the detonation velocity. The detonation velocity of NM measured in a steel tube at d = 1.133 g/cc and 87 ^{0}F is 6.495 km/s. This value is 1.64 higher than LEXFOAM. Density and detonation velocity are the two most important factors for clearing mines.

Critical Thickness Measurements Results:

From the results with several sizes of paper trays, it is clear that the tray with the lowest thickness (0.5" in height – the area of LEXFOAM was also 1" wide and 6" long) of LEXFOAM is easily detonated with a #6 electric cap. LEXFOAM may detonate below a thickness of 0.5" but it was difficult to insert the electric cap in such a thin layer. Critical diameter is important for condensed explosives. There is a diameter below which an explosive cannot detonate but for LEXFOAM thickness is also important. There is a critical thickness, which varies depending on the initiation method, below which LEXFOAM cannot detonate. This is important for connecting several mines with LEXFOAM for clearing them.

Confinement Results

The plastic tube as shown in Figure 2 (left) and steel hollow cylinders were used for the LEXFOAM confinement investigations. The effect of confinement of LEXFOAM in plastic and metal tubes is shown in Figure 2 (middle) and 2 (right) respectively. The dents were 5 mm and 17mm on witness plates for plastic and metal cylinders respectively. Generally the detonation velocity depends on the confinement, thickness and material of confinement. From the dents values it is clear the steel cylinder has a deeper dent than the plastic cylinder. The detonation waves travel several times in the steel tube before they break and they have a higher detonation velocity. As a result it is more effective. The confinement of LEXFOAM in a tube will reduce consumption LEXFOAM for mine clearance purposes.

Figure 2: The LEXFOAM confined in plastic tube and metal tube and it's effect.

Stability Results:

LEXFOAM sprayed on the ground and left for 18 hours was successfully detonated with a # 6 electric cap. We found a small crater on the soil, suggesting the LEXFOAM remained stable for at least 18 hours after being sprayed. The stability of the LEXFOAM depends on the temperature, and on the amount of LEXFOAM. LEXFOAM was sprayed on a 6” x 6” witness plate at 90 ^{0}Fas shown in Figure 3A and initiated with a # 6 electric cap. After 16 hours the LEXFOAM detonated with high order bending of the witness plate in all corners as shown in Figure3C. The boiling point of NM is 100 ^{0}C (212 ^{0}F). Its freezing point is –29 ^{0}C (-20 ^{0}F). The hydrocarbons blend propellant has a boiling range of –25 to 31 ^{0}F, suggesting LEXFOAM is not produced at ^{0}C. However, the LEXFOAM from MREL will

Figure 3: LEXFOAM stability after 16 hours and it's performance

remain stable at zero degrees because they use only propane propellant, which boils at –40 ^{0}F and freezes at –31 ^{0}F. Due to the high freezing point of nitromethane, LEXFOAM cannot be prepared in very cold regions of the World.

Mines Test Results:

Mine Type	Designation	Mine Case	No. of Foam Can	Results
AP	VS-50	Plastic	0.5	Fully neutralized
AP	VS-50	Plastic	0.5	Partly neutralize
AP	TS-50	Plastic	0.5	Fully neutralized
AP	PMD-6	Wooden	1	Partly neutralize
AP	PMD-6	Wooden	1	Fully neutralized
AP	PROM-1	Metal	1	Did not neutralize
AP	POMZ-2	Cast iron	2	Fully neutralized
AT	LPATM	Plastic	1.5	Fully neutralized
AT	LPATM	Plastic	1	Deflagration
AT	LMATM	Metal	1	Fully neutralized
AT	LMATM	Metal	1	Fully neutralized

Table 3. Different AP and AT mines neutralization with fully charged LEXFOAM
LPATM → Large Plastic case Anti-Tank Mine
LMATM→ Large Metal case Anti-Tank Mine

AP and AT mines are neutralized by high order using from one-half to two cans of LEXFOAM. Heavy steel PROM-1 AP and some blast resistant VS-50 and TS-50 mines failed to neutralize completely. The capability of neutralizing AP mines (i.e. POMZ-2, Steak mines) above ground have been demonstrated. Some AT mines were neutralized by deflagration (burning explosive). This suggests that the LEXFOAM has enough force to open the mine case without detonating the explosive. The majority of the mines tested were unfuzed. This is a worst scenario for testing mines. As a result more LEXFOAM may be needed to neutralize a mine compared to fuse mine. For small AP mines at least less than one can may be needed, while a blast resistance and/or heavy steel AP and AT mines may require at least two cans of LEXFOAM. The placement of the LEXFOAM on the mine is an important factor. The density of the foam increases with increasing atmospheric temperature. As a result the detonation velocity of the foam also increases. Therefore the performance of the foam increases. Our study on witness plates suggests that little confinement of the LEXFOAM works better than unconfined. This is one of the best systems to neutralize mines above ground and in hard to reach areas. LEXFOAM is nearly 100% effective for neutralizing any mines above 85 ^{0}F using two cans. Below 40 ^{0}F, the LEXFOAM capability of neutralizing mines degrades.

CONCLUSION

LEXFOAM neutralization technology is based on two non-explosive liquids which can be mixed in the field to produce liquid explosive foam when it disperses. The mines are neutralized by sympathetic detonation of the main explosive charges in landmines. The LEXFOAM Neutralization systems are effective against both AP and AT landmines. The effectiveness of the systems depends on atmospheric temperature and pressure. At higher temperature above 80 ^{0}F, LEXFOAM produces high-density foam and is more effective against mines. The amounts of hydrocarbons blend propellant in the LEXFOAM stock solution do not change the density of the LEXFOAM. Therefore its neutralization performance remains the same. LEXFOAM remains stable and effective for at least 12 hours after it has been sprayed, depending its thickness and environmental temperature. The confinement of LEXFOAM increases its performance. After mixing both components in a can, the mixture is still not an explosive.

Based on considerations of safe handling and storage, temperature stability, toxicity, availability and cost, it is clear that Hand-held systems based on NM and blend hydrocarbons propellant can be a preferred candidate for humanitarian demining applications. The major advantage of the LEXFOAM system is that it does not require explosives.

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