AN INSENSITIVE ALTERNATIVE TO THE PRESSED EXPLOSIVE LX-14

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ABSTRACT

A new series of high performance explosive formulations have been developed that show promise as a replacement for the current pressed explosive standard **LX-14**. The primary formulation was intended to be flexible enough to provide a range of performance parameters (e.g., detonation velocities of ±9% versus **LX-14**) while maintaining low IM sensitivity. Preliminary characterization has been completed for one case that was designed to have performance equivalent to **LX-14** and insensitive munitions properties equivalent to **PAX-2A**. The predicted performance, actual performance, small-scale hazard properties, NOL card gap, and Variable Confinement Cook-off Test (VCCT) results of the example (**DLE-P031**) was compared to **LX-14**, **PAX-2A**, **PBXW-11**, and **HMX**. Granular **DLE-P031** was generated using the water slurry manufacturing method which yielded an excellent molding powder that could be pressed to 99%+ of TMD. The **DLE-P031** was found to be no more sensitive to impact and friction than **LX-14** and **PAX-2A**. The LSGT indicated that the shock sensitivity of **DLE-P031** was nearly equivalent to that of **PAX-2A** and much less sensitive than **LX-14**.

INTRODUCTION

New high performance explosive formulations for pressed applications are currently being investigated that have been designed to equal the performance of **LX-14** and the insensitive munitions properties of **PAX-2A**. The predicted performance, actual performance, small-scale hazard properties, and Large Scale Gap Test (LSGT; NOL) of an example designated **DLE-P031** have been compared to **LX-14**, **PAX-2A**, **PBXW-11**, and **HMX**. The **LX-14** formulation containing 95.5% HMX and 4.5% unplasticized, inert binder suffers from shock and thermal sensitivity as indicated by poor LSGT results and detonations at low confinement in the Variable Confinement Cook-off Test (VCCT). The **PAX-2A** formulation containing 8.5% less HMX and employing an energetic binder/plasticizer system is a lower energy composition but performs exceptionally well in the LSGT and the VCCT. The **PBXW-11** formulation at 96% HMX and 4% plasticized, inert binder is a slightly higher energy composition than **LX-14** and performs very well in the VCCT but performs poorly in the LSGT because of the high HMX content. The **DLE-P031** formulation, that is iso-energetic with **LX-14**, contained less HMX than **PAX-2A** to reduce the shock sensitivity and employed an energetic binder/plasticizer system to help reduce the thermal sensitivity. The explosive performance level of **LX-14** was achieved through the use of the moderately energetic but very dense Dinitrotetraoxadiazatetracyclododecane (TEX) shown in Figure 1. The energetic binder/plasticizer system efficiently coated the energetic fillers and produced an excellent molding powder from which pressed articles were readily obtained. We report here the production of **DLE-P031** and its characterization for impact, friction, ESD, thermal, and shock sensitivity. We anticipate that these formulations will find application in the Future Combat System (FCS).

RESULTS AND DISCUSSION

INGREDIENTS

The major energetic ingredient in this family of explosives is HMX that was chosen for its high energy density and availability (Figure 1). The minor energetic component was TEX (Dinitrotetraoxadiazatetracyclododecane) which was originally developed as a precursor to CL-20 and was found to have excellent impact, friction, and thermal stability.[1] Even though the total energy of detonation for TEX is less than that of PETN, the high density and stability made it attractive for this application. In addition, we anticipate that TEX will have reasonable production costs relative to HMX. The energetic binder system was chosen to make up for the energy density lost to TEX coupled with potential decomposition properties expected to enhance cook-off survivability. The binder was also expected to produce superior coating, pressing, and machining properties.

FORMULATION AND CHARACTERIZATION OF HMX/TEX EXPLOSIVE MOLDING POWDERS

The objective of the formulation effort was to provide a set of explosives that exhibit performance equal to or better than **LX-14** and low sensitivity equal to **PAX-2A**. Using **PAX-2A** as a model and the CHEETAH thermochemical code, it was desirable to reduce the concentration of HMX in the formulation too less than that of **PAX-2A** and thereby reduce overall sensitivity.[2] To make up for the resultant performance loss without adversely affecting the sensitivity gain, the stable, high density, and somewhat energetic TEX was incrementally added until the performance and the formulation density approached or exceeded that of **LX-14**. The binder concentration was then adjusted to balance the formulation performance and density with that of **LX-14**. The performance parameters of the example formulation **DLE-P031** were calculated and compared to **LX-14**, **PAX-2A**, **PBXW-11**, and **HMX** (Table I).[2]

Molding powders of **DLE-P031** were granulated using a modified water slurry method that minimizes environmental impact by significantly reducing the use of organic solvents.[3,4] By careful optimization of mixing parameters such as water:energetic filler ratio, lacquer addition rate, and impeller rate, it was possible to produce exceptional molding powders while reducing the waste stream. All granulated materials were subjected to a full test matrix including: (1) laboratory scale hazard (impact, friction, ESD, and thermal sensitivity), (2) chemical (HPLC and volatiles), and (3) physical properties (sieve analysis, bulk density, pressed density, color, and shape). Pellets for the LSGT were pressed to 99% of TMD.

Several granulations yielded material for the initial characterization of **DLE-P031** (Figure 2 and Table II). The impact, friction, and ESD results indicated that **DLE-P031** was less sensitive than **LX-14**, **PAX-2A**, and **PBXW-11**. The thermal sensitivity of each explosive was low as determined by SBAT and DSC. However, the SBAT showed two distinct exotherm regions separated by 50 °C that correspond to decomposition of the plasticizer followed by the decomposition of the energetic fillers. That behavior was observed to a lesser extent in the DSC by the appearance of a broad peak. It was hoped that the early decomposition of the plasticizer would contribute to a “soft” ignition and reduction of the reaction violence of the

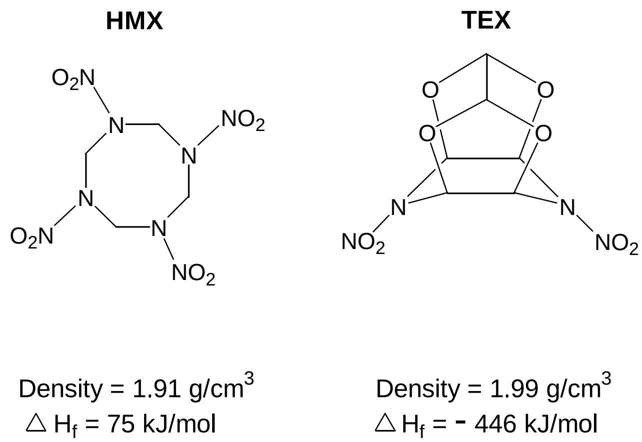

Figure 1. The **DLE-P031** energetic filler ingredients with corresponding densities and heats of formation.

Table I. Calculated Performance Comparison at 99% TMD

Formulation	Density 99%TMD (g/cc)	Detonation Pressure (kbar)	Detonation Velocity (km/s)	Cylinder Expansion Energy @V/V_0=6.5 (kJ/cc)	Total Energy (kJ/cc)
DLE-P031	1.83	344	8.77	8.69	10.42
LX-14 (95.5% HMX)	1.84	344	8.80	8.59	10.27
PAX-2A (87% HMX)	1.78	324	8.60	8.45	10.24
PBXW-11 (96% HMX)	1.83	348	8.83	8.72	10.45
HMX (100%)	1.89	384	9.23	9.38	10.98

explosive during a slow cook-off situation (see below). Each of the explosives was similarly stable under VTS conditions. The LSGT indicated that the shock sensitivity of **DLE-P031** approached that of **PAX-2A** and was significantly improved versus **LX-14** (Table II and Figure 3).

VARIABLE CONFINEMENT COOK OFF TEST (VCCT)

The VCCT test apparatus is shown in Figure 4.[5] For each test, three 1" pellets were stacked (total length was 2.5") inside a 0.1" thick aluminum sleeve that was inserted into a steel confinement sleeve. The steel confinement sleeves ranged in thickness from 0.015” to 0.105”.

Figure 2. The **DLE-P031** granules and pressed pellets.

Table II. Small Scale Hazards Property Comparison

Formulation	DLE-P031	LX-14	PAX-2A	PBXW-11	HMX
ABL Impact (cm)[a]	26	17	17	21	3.5
ABL Frict. (psi @ x ft/s)[b]	560 @ 8	420 @ 8	320 @ 8	240 @ 8	50 @ 6
TC ESD (J)[c]	>8	>8	>8	>8	6.5
SBAT (exotherm onset, °C)[d]	149, 218	196	193	184	185
DSC (exotherm onset, °C)	278 (broad)	282	282	287	250
VTS (ml/g)[e]	0.20	0.20	0.25	0.30	0.07
LSGT (pres to det, kbar)[f,g]	38.9	22.8	44.6	21.0	10.2

[a]Threshold Initiation Level (TIL) for 20 no-fire drops per drop height. [b]TIL for 20 no-fires. [c]50% ignition point. [d]Simulated Bulk Autoignition Temperature measures the ability of a sample to absorb heat where an exotherm <107 °C indicates a sensitive material. [e]Vacuum Thermal Stability at 100 °C for 48 hr. [f] Large Scale Gap Test (LSGT); in this case NOL card gap, see: Department of Defense Explosives Hazard Classification Procedures (Army TB 700-2). [g]The reported value is the pressure required to produce a detonation response.

Two mica band heaters were placed around the entire assembly. The steel confinement sleeve was placed between recessed witness plates that were held together with four retaining bolts. The assembly was then heated at 6 °F/hr. until a reaction took place. The apparatus and any unburned explosive were recovered for reaction classification based on the appearance and size of the fixture and steel sleeve pieces.

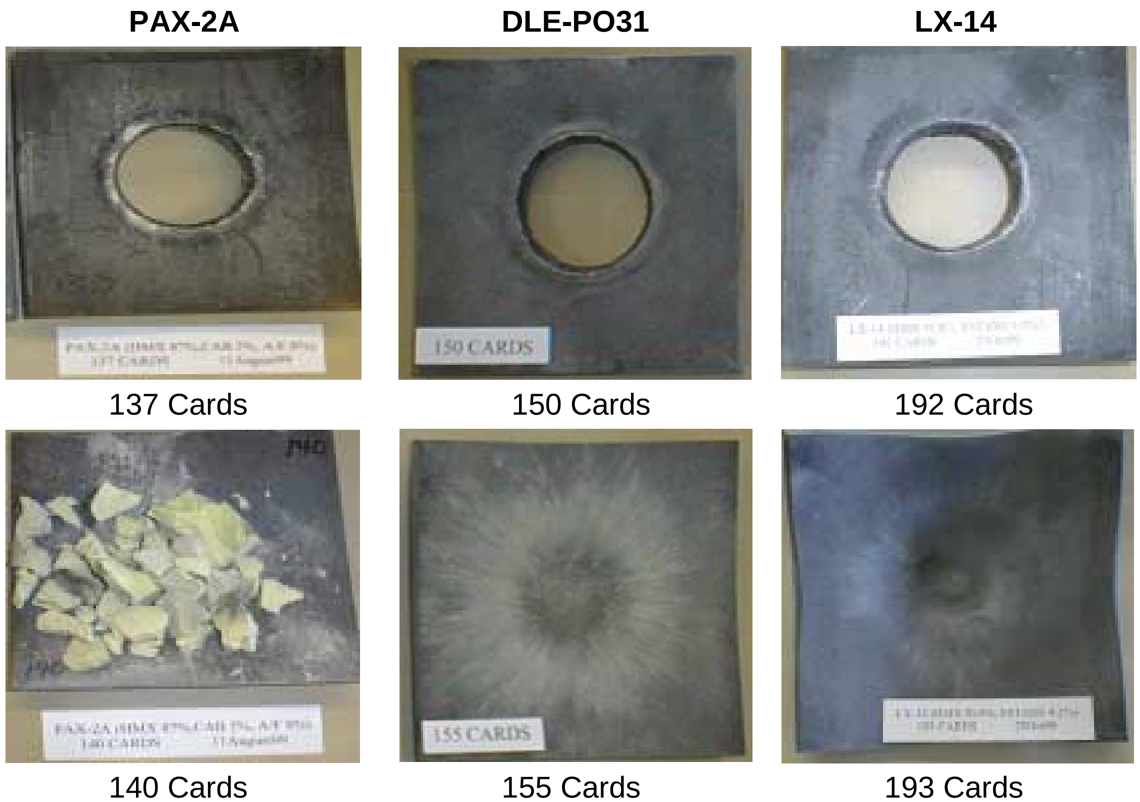

Figure 3. A comparison of the NOL card gap of **DLE-P031** to **PAX-2A** and **LX-14**.

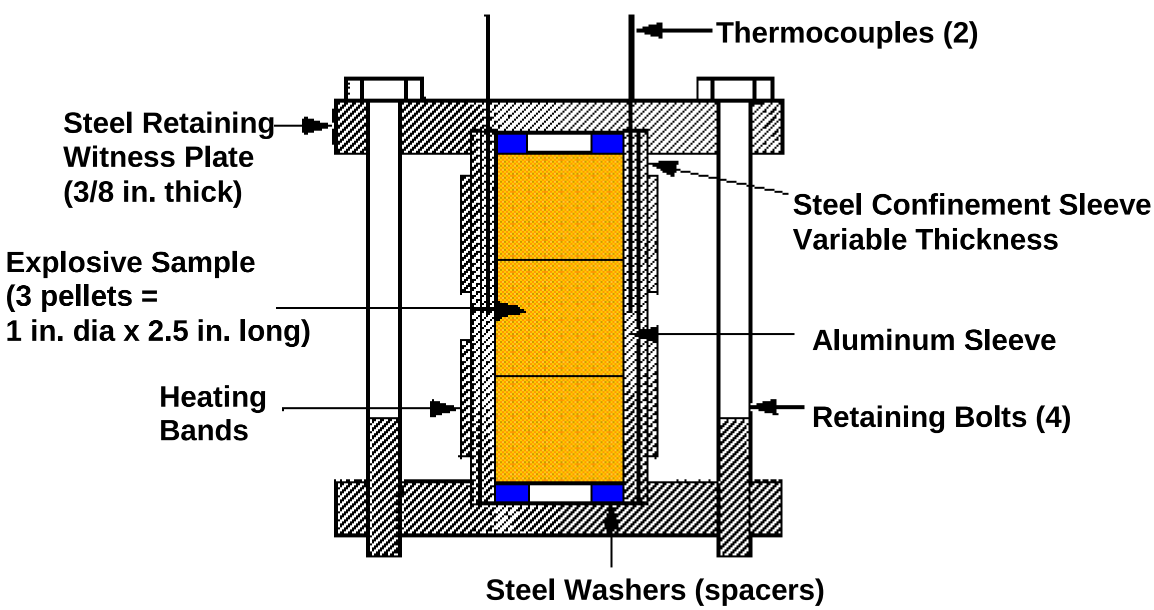

Figure 4. The Variable Confinement Cook off Test (VCCT) apparatus.

The VCCT result for **DLE-P031**, **PAX-2A**, and **LX-14** at a confinement of 0.075" is shown in Figure 5. The **PAX-2A** formulation at 8.5% less HMX than **LX-14** and employing an energetic binder/plasticizer system performed exceptionally well in this test. The VCCT fixture remained comparatively intact with two bolts broken, some deformation of the witness plates, and the recovery of some unburned **PAX-2A** that resulted in a deflagration classification. The **LX-14** formulation containing 95.5% HMX and 4.5% unplasticized, inert binder suffered a detonation reaction which was characterized by the loss of all four bolts and both witness plates having clean holes punched. The **PBXW-11** formulation (not shown) at 96% HMX and 4% plasticized, inert binder performed similar to **PAX-2A** at the 0.075" confinement with a deflagration reaction. Thus, it was thought that the **DLE-P031** formulation that employed less HMX than **PAX-2A** and an energetic binder/plasticizer system like **PAX-2A** would perform similar to **PAX-2A** in the VCCT. That was not the case, though the **DLE-P031** formulation (partial detonation) was slightly more stable than **LX-14**, the expected deflagration reaction has not yet been obtained. However, since the temperature of reaction for **DLE-P031** was 14 °C (25 °F) greater than that of **PAX-2A**, it may be possible to take advantage of the stability of **DLE-P031** at higher temperature (Figure 6).

Finally, other insensitive formulations can be envisioned where a highly energetic ingredient (e.g., CL-20) is employed at low concentration to give a composition that still matches **LX-14** performance. For example, a formulation that contains a low concentration of CL-20 has a TMD of 1.91 g/cc, a calculated C-J pressure of 359 kbar, and shock velocity of 8.79 km/s. Similarly, a formulation that contains CL-20 and 15% binder has a TMD of 1.89 g/cc, a calculated C-J pressure of 356 kbar, and shock velocity of 8.78 km/s. Thus, this energetic binder system allows very high performance explosive compositions to be obtained with low solids loadings and accordingly excellent hazard properties.

CONCLUSION

This study has provided a new series of high energy density explosive formulations that equal or exceed the performance of **LX-14** but approach the low sensitivity of **PAX-2A**. The example formulation, **DLE-P031**, was generated as a molding powder by water slurry granulation and was shown to be less sensitive in small scale hazard testing than the comparative samples. The LSGT indicated that the shock sensitivity of **DLE-P031** was nearly equivalent to that of **PAX-2A** and much less sensitive than **LX-14**. The **DLE-P031** formulation was fairly reactive at intermediate confinement in the slow cook-off test but less reactive than **LX-14**. Because the VCCT reaction of **DLE-P031** occurred four hours subsequent to that of **PAX-2A**, the **DLE-P031** formulation has demonstrated higher temperature stability. The low hazard sensitivity, high performance, and formulation versatility of these HMX/TEX formulations provide an excellent alternative for the FCS application.

	PAX-2A	DLE-PO31	LX-14

	PAX-2A	DLE-PO31	LX-14
Reaction Temp (°C):	**177**	**191**	**186**
Reaction Level:	**Deflagration**	**Partial Detonation**	**Detonation**

Reaction level ranking: Burn < Pressure Rupture < Deflagration < Explosion < Partial Detonation < Detonation

Figure 5. The VCCT of **DLE-P031** compared to **PAX-2A** and **LX-14** at a confinement of 0.075” (calc. burst pressure: 12,976 psi).

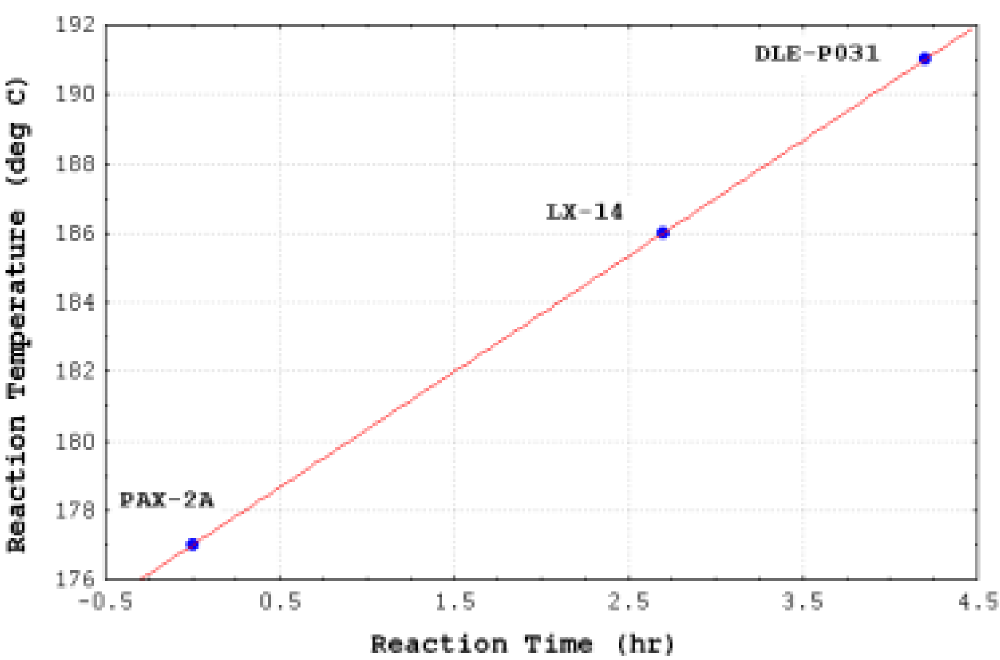

Figure 6. Plot of VCCT reaction temperature versus time of reaction for **DLE-P031**, **PAX-2A** (time = 0), and **LX-14**.

REFERENCES

[1] (a) Wardle, R. B.; Highsmith, T.K.; Braithwaite, P.C., "Improved Synthesis, Characterization and Initial Explosives Formulations of TEX (Dinitrotetraoxadiazaisowurtizitane)," Material Research Society 1995 Fall Meeting, Boston, Massachusetts, 27 November - 1 December 1995. (b) Braithwaite, P.C.; Edwards, W.W.; Hajik, R. M.; Highsmith, T. K.; Lund, R. K.; Wardle, R. B., "TEX a Promising New Insensitive High Explosive," Proceedings of the 29th International Annual Conference of ICT, Karlsruhe, Germany, June 30 - July 3, 1998.

[2] *Cheetah 2.0*; Fried, L. E.; Howard, W. M.; Souers, P. C.; Lawrence Livermore National Laboratory: 1998.

[3] See: (a) Kim, H. S.; Kim, H. S. U.S. Patent 5,565,651, 1996. (b) Wright, S. B. U.S. Patent 3,296,041, 1967. (c) Stott, B. A., "An Evaluation of PBXN-2, A High-Energy, High-Strength, Nylon Bonded Explosive," NAVWEPS Report 7057, May 1960, NOTS, China Lake, CA (Unclassified).

[4] Lee, K.E. Unpublished results.

[5] Alexander, K.; Gibson, K.; Baudler, B., "Development of the Variable Confinement Cookoff Tests," IHTR1840, IH-NSWC September 1996.