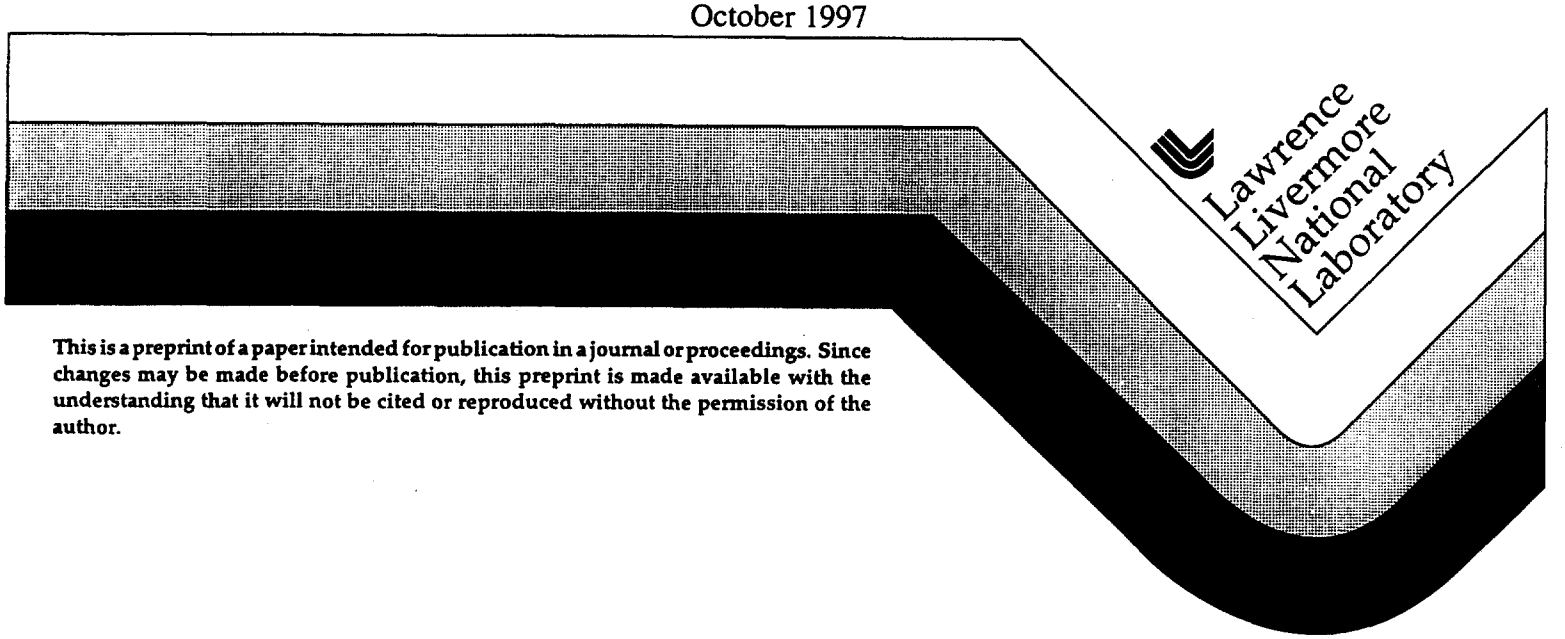
UCRL-JC-127540
PREPRINT

RX-08-HD, A Low-Viscosity, Injection-Moldable Explosive For Filling Tortuous Paths

D. Mark Hoffman
Edward S. Jessop
Rosalind W. Swansiger

This paper is prepared for submittal to the
ADPA Insensitive Munitions and Energetics Technology Symposium
October 6-9, 1997, Tampa, Florida

October 1997



RX-08-HD, A LOW-VISCOSITY, INJECTION-MOLDABLE EXPLOSIVE FOR FILLING TORTUOUS PATHS*

D. Mark Hoffman, Edward S. Jessop and Rosalind W. Swansiger
Energetic Materials Center
Lawrence Livermore National Laboratory
Livermore, CA 94550

Introduction

Historically, cast-cure[1], extrusion cast[2], and paste extrudable[3] explosives used in DOE and DOD applications have not been designed for transferring through long tortuous paths or into fine 3-dimensional shapes. Typical, low-shear rate viscosities were quite high (1,000,000 poise). For uniform flow in small channels and capillaries where the flow rate varies with the 4th power of the radius, low viscosity is a critical requirement. To minimize viscosity, bimodal mixtures of HMX crystals were used based on the theoretical work of Farris[4] and previous work with TATB.[5] To allow the crystalline explosive to "flow" a lubricating fluid is required. The energetic liquid trimethyl ethane trinitrate (TMETN) was used as the lubricant to maximize explosive energy. TMETN is a liquid nitrate ester which requires stabilization with conventional free radical stabilizers such as 2-nitrodiphenylamine (2-NDPA), methyl-nitroanaline (MNA), or ethyl centrylite (EC). Since these injection moldable explosives are expected to cure in place, a polyesterurethane binder based on polymeric isocyanate of hexamethylene diisocyanate (N-100) and polycaprolactone polyols is dissolved in the TMETN. The solubility of the polymer precursors in TMETN also reduces the energetic liquids sensitivity. Finally, the latent cure catalyst Dabco T-131 was used to minimize shrinkage associated with thermal expansion, reduce costs associated with oven cures, to give 4-6 hour potlife and overnight cure to handling strength.

Experimental

1. **Materials:** Bimodal mixes of HMX crystals obtained from Holston Army Ammunition Plant (HAAP) were blended in optimum 72.5/27.5 ratios of coarse to fine. In our study, coarse HMX crystals ranged in mean particle size between 40 - 250 μm. Fine HMX crystals ranged in mean particle size between 3 – 20 μm. Particle size analysis of the various cuts of HMX was determined using a Malvern Laser Light Scattering Apparatus. Two flavors of the energetic plasticizer trimethylolethanetrinitrate (TMETN) was purchased from Trojan Chemical corporation and donated by NWC-IH Yorktown detachment. The major difference between the two TMETN explosive liquids was the stabilizer. Trojan TMETN was stabilized with 2-nitrodiphenylamine (2-NDPA) while NWC-IH TMETN was stabilized with ethyl centralite (EC). The polyurethane binder is polymerized from polymeric hexamethylene diisocyanate (Desmondur N-100) manufactured by Mobay Corporation and polycaprolactone polyols (Tone 260 and Tone 6000) manufacutred by Union Carbide corporation. A latent cure catalyst, Dabco T-131,

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

manufactured by Air Products provided 4-6 h pot life and overnight cure to handling strength at ambient.

2. **Formulation:** A series of 74% solids formulations were prepared as indicated in Table 1 using various coarse and fine grades of HMX. These injection moldable explosives were formulated from a solution of TMETN and the Tone polyester polyols called RX-44-BJ combined with the bimodal distribution of HMX in a sigma-blade mixer. The TMETN and Tone polyols were dissolved at 60°C for several hours with stirring then coolde to ambient. The T-131 mercaptotin catalyst was added and allowed to coordinate for 10-20 minutes. The HMX solids were added and mixed remotely under vacuum to constant viscosity. This RX-08-series paste could be stored for several weeks to months without degradation of catalyst. Prior to use, the injection moldable paste and N-100 isocyanate were mixed and allowed to cure. Table 2 lists the test matrix of formulations evaluated in 50-g mixes and their 0.1 sec-1 shear rate viscosity and dynamic viscosity which were used to characterize their rheology. The rheological behavior of these materials was evaluated by conventional dynamic and steady shear viscosity measurements in a parallel plate rheometer. Estimates of thixotropy were made by strain sweep measurements. The viscosity at low shear rates was used to down-select RX-08-HD from these formulations (see Table 2).

Table 1. Composition of RX-08-Series formulations:

Composition	% by weight	% by volume
HMX	73.95	66.70
TMETN	19.33	22.59
Tone 260	5.04	8.10
Tone 6000	0.78	1.25
Desmondur N-100	0.91	1.36
Dabco T-131	0.007	
Total	100.00	100

Table 2. Viscosity and HMX composition of various RX-08 series formulations.

ID	$\eta^*(.1)$ kp	η (.1) kp	Coarse	Fine
-GX	53.0	38.9	Class 1	5 μ FEM
-GY	87	70.5	>43 μ C2	5 μ FEM
GZ	51.4	41.4	>43 μ LX04	<43 μ LX04
HA	102.	87	>43 μ C2	<43 μ LX04
HB	63.8	35.4	>43 μ LX04	<43 μ C2
HC	1800	103	>43 μ C2	<43 μ C2
HD	35.4	30.9	>43 μ LX04	class 5
HE	88	70.5	>43 μ C2	class 5
HF	267		Class 1 (250 m)	3μ FEM

Down Selection Process: Results and Discussion

1. **Performance:** Prior to extensive formulation efforts, performance calculations using the Cheetah thermochemical code[6] were carried out to compare various energetic plasticizers such as, FEFO, TMETN, TMETN/TEGDN 75/25, BDNPA/F 50/50 and DOP, at the compositions given in Table 1. Since the formulations should have minimal voids if deaerated properly, the thermochemical code was run at the maximum density (TMD). Predicted detonation and metal acceleration characteristics are given in Table 3. Performance characteristics of the energetic and inert plasticizers varied as:

FEFO > TMETN > NG/TA > BDNPA/F >> DOA.

Although FEFO formulations were predicted to be more energetic and have higher thermal stability, measurements by Sandia National Laboratories indicate possible compatibility questions with metals may exist[8]. TMETN/TEGDN blends reduced sensitivity compared to pure TMETN, but recently TEGDN has been shown to degrade in storage. Because of its excellent energy and current use in DOE weapons systems[7], TMETN was selected for evaluation in injection moldable formulations. With only about 6% less energy than TMETN, BDNPA/F is also an excellent plasticizer, having been used in DOD and DOE applications, but recently its cost and availability have been of concern.

Table 3. Cheetah performance predictions RX-08-like formulations in Table 1 with different plasticizers showed FEFO > TMETN > NG/TA > BDNPA/F >> DOP.

CJ condition	TMETN	FEFO	NG/TA	BDNPA/F	DOP
P (GPa)	28.61	29.52	28.19	26.99	17.38
E	3.52	3.60	3.46	3.32	2.13
T (°C)	4010	4050	3982	3906	3326
V(det) mm/μs	8.23	8.315	8.186	8.047	6.771
V/V_o (Cyl)					
2.2	-5.92	-6.02	-5.82	-5.60	-3.92
E_{rel} HMX	79	81	78	75	52
E_{mcc}	-9.473	-9.566	-9.323	-9.124	-7.335
$E_{thermal}$	0	0	0	0	-.086
TMD (g/cc)	1.7184	1.7521	1.7154	1.6963	1.5467

2. **Small Scale Safety tests.** All explosives developed at LLNL are subjected to small scale safety tests including impact sensitivity, friction and thermal stability prior to scale up and use in prototype devices. Table 4 shows these tests for developmental RX-08-series formulations. A thorough critique of various small scale tests is given elsewhere.[9]

Table 4. Small Scale Safety Data on Explosive in Table 2

Formulation	DH(50) (cm)	Friction (Kg)	DSC (°C)	CRT (cc/g)	Spark
RX-08-GX	65.6	19.2	257	.004	not sensitive
RX-08-GY	138.7	24			not sensitive
RX-08-GZ	122.6	22.8	240		not sensitive
RX-08-HA	137.4	36.0			not sensitive
RX-08-HB	70.9	22.8			not sensitive
RX-08-HC	82.5	20.4	230		not sensitive
RX-08-HD	78.5	19.2	240	0.004	not sensitive
RX-08-HE	112	19.2			not sensitive
RX-08-HF			235		not sensitive

3. Rheology: Flow characteristics of suspensions of explosive solids in explosive liquids with polymeric binders are not well understood. Because this cast cure explosive will be used to fill devices under low (100-400 psi) pressure and at relatively low shear rates, parallel plate rheometry was chosen to characterize the uncured RX-08-series explosives. The equations for calculating shear stress, shear rate, and viscosity are:

Steady shear:

$$\tau = 2T/\pi r^3 \quad (1)$$
$$\gamma = \Omega r/h \quad (2)$$
$$\eta = \tau/\gamma \quad (3)$$
$$N_1 - N_2 = 4F_z/\pi r^2 \quad (4)$$

where, τ is the shear stress, T is the torque, r is the radius, γ is the shear rate, Ω is the rotational speed, h is the plate separation, η is the viscosity, N_1 and N_2 are first and second normal stress differences, and F_z is the force along the z direction (up).

Oscillatory (dynamic) viscosity:

$$\eta^* = [(\eta')^2 + (\eta'')^2]^{1/2} = G^*/\omega (5)$$
$$G^* = [(G')^2 + (G'')^2]^{1/2} \quad (6)$$
$$\eta' = G''/\omega \quad (7)$$
$$\eta'' = G'/\omega \quad (8)$$

where G^* or η^* indicates the complex shear modulus or viscosity, and single prime indicates the real component, double prime the imaginary component and ω is the frequency of oscillation in radians per second.

Since these pastes are non-Newtonian plots of viscosity versus shear rate or frequency do not yield constant values of η. Instead a simple power law[10] was used to describe the apparent viscosity as a function of shear rate:

$$\eta = K\dot{\gamma}^{(n-1)} \quad (8) \quad \text{or} \quad \eta^* = K\omega^{(n-1)} \quad (9)$$

where K and n are constants. Figure 1 shows the apparent viscosity as a function of shear rate and frequency for RX-08-HD. Note that the steady shear viscosity measured between parallel plates deviates at increasing shear rate from the dynamic viscosity measured at 10% strain because of inertial or secondary flow effects.

The shear storage and loss moduli can be measured dynamically as a function of strain amplitude using equation 5. A simplistic attempt to estimate thixotropic behavior and yield stresses of these filled pastes was made using the relationship:

$$\sigma_{12}(0) = G'(\omega)\gamma_{12}\cos(\delta) \quad (10)$$

Where $\sigma_{12}(0)$ is the shear stress; γ_{12} is the shear rate and δ is the phase angle. In Figure 2 first and second strain sweep measurements of dynamic viscosity and shear stress (from equation 10) are shown as a function of strain amplitude at 1 Hz (6.28 rad/s) for RX-08-HD. The apparent dynamic viscosity of the second run is initially lower than the first at low amplitudes and approaches the first run viscosity above 3% strain. The shear stress approaches a limiting value of about 3 KPa reminiscent of a Bingham fluid. The second run has an entirely different slope. Table 5 lists the K and n values of the RX-08-series explosive paste formulations.

Table 5. Rheological characteristics of the RX-08-series paste formulations.

Formulation	K	n	R
RX-08-GX	980	0.404	0.979
RX-08-GY	1383	0.348	0.982
RX-08-GZ	889	0.437	0.974
RX-08-HA	1601	0.296	0.991
RX-08-HB	1009	0.381	0.974
RX-08-HC	20925	0.232	0.992
RX-08-HDy	704	0.424	0.977
RX-08-HDw	703	0.424	0.997
RX-08-HE	1396	0.346	0.984
RX-08-HF	3753	0.269	0.993

RX-08-series explosive filling characteristics were visually evaluated on a 50-g deaerator loader. This device consists of two pistons above and below an orifice plate. The paste explosive is loaded into the upper chamber and passed through the orifice plate under vacuum to remove any entrapped air. The lower piston is extended driving the explosive out a tube just below the orifice into the mold. A polycarbonate cylindrical

mold (2.34-cm internal diameter by 2.4-cm high) with a copper mandrill (1.27 cm diameter by 1.27 cm high offset from the center 0.9-cm) was filled with each explosive in the series. Two configurations are possible, as shown in Figure 3. Explosive can either be injected over the copper mandrill or away from it. Low viscosity RX-08-series explosives (-GX, GZ, and -HD) when injected over the mandrill fill in three phases. First the mandrill is covered and the explosive starts down the small side. Next it bridges and enters the vacuum line. At this point the vacuum must be closed and fill continues until the part is completely filled. The alternate configuration (fill side away from the mandrill) loaded better. The low viscosity explosive flowed down the side, to the bottom and part way around the mandrill before filling the upper section over the mandrill and bridging. With good vacuum low viscosity formulations could fill the mold completely without voids. Intermediate viscosity RX-08-series explosives loaded (-GY, -HB, –HF, -HA and HE) tend to bridge before completely filling the large gap (.38 cm). Vacuum had to be turned off before the device was half full. This results in small voids along the top of the mold. High viscosity paste (-HC) did not bridge badly or flow into the vacuum line until very near the end of the fill. However, this formulation filled slowly, was difficult to deaerate and tended to relax after pressure release forming small voids along the edge of the mold. Based on the rheological and small-scale safety results, RX-08-HD was down selected for further evaluation.

Results and Discussion: RX-08-HD

Upon completion of the selection process, extensive testing and scale up of RX-08-HD was initiated. The following are some of the results.

1. Compatibility: Attempts to identify any unwanted synergistic reactions between RX-08-HD and materials which were used or might be used in contact with the explosive were made by chemical reactivity tests of 1:1 mixtures held at 80°C for 22 hours. The gas generated during thermal treatment are collected and analyzed using a GC. When large quantities of gas are generated compared to the explosive itself, the explosive/material mixture will generally be incompatible. Table 6 lists materials evaluated by CRT in four categories, polymers and elastomers, adhesives, metals and some explosives.

Compatibility of RX-08-HD with polymers and elastomers in general is good. Polycarbonate plastic and neoprene o-rings generated 1.5-2 times the gas observed in RX-08-HD alone. Ethylene-co-vinyl alcohol copolymers gave about eight times more gas than RX-08-HD. These polymers should probably not be used for long-term applications without further evaluation. Self-lubricating nylon filled with MoS also showed above normal out-gassing. The CRT test addresses only the adverse reaction of the explosive with the polymer. It is also possible for the liquid explosive, TMETN, to be embibed by the polymer. Currently the CRT test cannot be used to evaluate polymer/TMETN solubility.

Four types of adhesive chemistries, silicones, urethanes, epoxies and cyanoacrylates were evaluated for compatibility with RX-08-HD using the CRT. The concentrations of gasses generated by 1:1 mixtures of RX-08-HD with cured adhesive varied according to the adhesive chemistry as follows:

$$\text{Silicones} < \text{urethanes} < \text{epoxies} \approx \text{cyanoacrylates}$$

Metal compatibility with RX-08-HD is quite good. Of the 9 metals tested only Molybdenum showed modest (3-4X) nitrous oxide generation. Molybdenum shaped charges have been prepared and test fired in short (3-6 mo) time frames. The large concentrations of gas generated by Hg are due to an erroneously high CRT temperature (120°C vs 80°C) used in this test. None of the metals evaluated to date show major degradation or synergystic reactions with RX-08-HD. It should be noted that on one dissassembly of a copper liner shaped charge, a very light blue green tint was observed near the Cu/Al interface. This might indicate that the TMETN is acting as a weak galvanic couple.

Three plastic bonded explosives were evaluated with RX-08-HD for compatibility using the CRT. Two HMX based explosives (LX-10 and LX-14) and one TATB based explosive (LX-17-1) all produced low quantities of gas and can be tentatively considered compatible. The HMX based explosives have been used as booster pellets along with PBX-N5, which is similar to LX-10 for initiating RX-08-HD.

Caveats associated with CRT measurements as an indication of materials compatibility with explosives include:

1. Multicomponent interactions, such as galvanic couples which accelerate corrosion of metals, may not be observed.
2. Property degradation due to solubility of the polymer, elastomer or adhesive in the liquid TMETN explosive liquid is not indicated by this test.
3. Global environment interactions between explosive and, for example, moisture or air at component interfaces can not be evaluated by these tests.

Since CRT on specific components can only address the reaction of the explosive with the component tested, complete mock-up or accelerated aging units should be prepared and evaluated for any proposed application with this explosive. CRT serves as an excellent screening tool, but only a screening tool. It should be noted, however, that HMX/TMETN formulations are currently in use in the DOD.

Table 6. Compatibility estimates of RX-08-HD with polymers, elastomers and adhesives were based on the chemical reactivity test (CRT).

CRT:	N2	O	CO	NO	CO2	N2O	TOTAL	Result
RX08HD					0.004		0.004	
RX08HD-1c	0.002				0.005		0.007	
Polymers & Elastomers								
PC*	0.0125	0.0035			0.0075		0.0235	RX08HD 0c
PMMA	0.0125				0.0065		0.019	2 runs
Delrin	0.008				0.011		0.019	
Urethane	0.003				0.007		0.01	
vinyl (PVC)	0.002				0.005		0.007	
Pethylene	0.003				0.007		0.01	
TPX	0.00							
Nylon/MoS	0.005			0.0165	0.0075		0.029	T-seal
Tygon	0.0055				0.006		0.0115	2 runs
EPDM	0.006				0.007		0.013	o-rings
C-PVC	0.0055			0.0025	0.0075		0.0155	2 runs
Viton	0.0085	0.001		0	0.006		0.0155	o-rings
Buna	0.016			0.023	0.013		0.052	o-ring
VCE (EVA)	0.006		0.004	0.044	0.02	0.005	0.079	pads - *incomp*
Neoprene	0.004			0.0075	0.0065		0.018	wt loss
Teflon	0.0115				0.006		0.0175	
Adhesives								
Urethanes								
Halthane	0.0075				0.0115		0.019	73-18
LW520	0.02	0.003			0.007		0.03	
APC 2.5	0.002				0.005		0.007	**Silicones**
RTV 732*							0	gives off HAc
DC 3145*	0.003				0.006		0.009	gives off MeOH
Tracon 2135	0.007			0.012	0.012	0	0.031	**Epoxies**
Torseal	0.006				0.032	0.004	0.042	
Epon 828	0.0125			0.0225	0.0425	0.004	0.0855	Versamid 140
Hysol black	0.006				0.0225	0.0055	0.034	
Hysol blue	0.0075			0.0115	0.018	0.004	0.041	
E-910					0.045		0.045	**Cyanoacrylate**
Metals	**N2**	**O**	**CO**	**NO**	**CO2**	**N2O**	**TOTAL**	**Result**
SS-304*	0.002	0		0	0.005		0.007	2 runs
SS-304	0.005			0	0.005		0.01	
Mo	0.005			0.1775	0.006		0.1885	2 runs
Cu	0.005	0			0.006		0.011	
Al	0.006				0.006		0.012	2 runs
W	0	0		0	0.004		0.004	2 runs
W:Ni:Fe	0.002	0		0	0.0055		0.008	2 runs
In	0.003	0		0	0.005		0.008	2 runs
Hg	0.2105		0.0895	0.307	0.2355	0.086	0.9285	2 runs
Ag	0.006				0.0065		0.0125	2 runs
Explosives								
LX-10					0.004		0.004	
LX-14	0.002				0.005		0.007	
LX-17-1	0.0025				0.008		0.0105	

2. **Cure characteristics**: The cure characteristics of RX-08-HD using Air Products catalyst, T-131, are very sensitive to the concentration of the catalyst used. Concentrations from 10 to 300 ppm were evaluated using parallel plate rheometery with the RMS 800 mechanical spectrometer and Fourier transform infrared spectroscopy. Two master batches of RX-44-BJ with 0.2% (20,000 ppm) Dabco T-131 and without any catalyst were prepared. These lacquers were blended to produce ten RX-08-HD formulations with 10, 20, 30, 50, 70, 100, 200, 300, 400 and 500 ppm T-131 catalyst. The viscosity as a function of time at 1 Hz for different catalyst levels of RX-08-HD was found to vary between 2 hours to 6 hours as shown in Figure 4. Above 70 ppm no significant increase in cure rate was observed. Concentrations of catalyst below 10 ppm were not evaluated. Volumetric shrinkage during cure by mercury dilatometry[11] at 30°C was 0.14%.

3. **Mechanical Properties:** RX-08-HD when cured has the consistency of a pencil eraser. Dynamic shear moduli were measured from –150 to 80°C at 5 frequencies. In Figure 5 the 1 Hz data shows vitrification of the TMETN/Binder at about –50C, melting of the TMETN around 0°C and a 2-MPa shear modulus above zero. Assuming Poisson's ratio of 0.43, from other similar formulations, the bulk and tensile moduli can be estimated from elasticity theory. Creep can be estimated using time-temperature superposition. At ambient under moderate stresses, creep is predicted to be small.

4. The volumetric expansion coefficient of RX-08-HD was measured very accurately using a mercury dilatometer from –10 to 80°C. Over this temperature range the expansion coefficient, α was:

$$\alpha = (\Delta V/\Delta T)/V = 3.675\ (\pm 0.009)\ X\ 10^{-4}/°C \qquad (11)$$

where V is the volume and T is the temperature in degrees Celsius.

6. **Scale up and device loading**. Shaped charges containing up to 130 lbs of explosive and other devices have been successfully loaded and tested with RX-08-HD. Figure 6 shows a schematic of the fixturing used to load a 500 mm shaped charge. Care must be taken to insure good vacuum. Inattention to flow characteristics, vacuum, blind holes or leaks can result in voids. Careful attention to detail yields excellent fills. RX-08-HD produces an even, uniform jet with appropriate metallurgy and shape charge design. Figure 7 shows the IC camera photographs of a shaped charge in opreation. With good design, good metallurgy and a good load of RX-08-HD, a uniform get produced the result shown if Figure 8.

CONCLUSIONS

RX-08-HD is a new, low-viscosity, injection moldable explosive that can be extruded into complex, void-free shapes. Combined with appropriate design and other aspects of weaponization, RX-08-HD has produced outstanding results.

REFERENCES:

1. D.M. Hoffman, C.O. Pruneda, E.S. Jessop and C.M. Walkup, *RX-35-BX: A Low-Vulnerability, High-Performance Explosive for Main-Charge Applications*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-UR-110363 (1992).
2. E. von Holtz, K. J. Scribner, R. Whipple, and J. Carley, *Paste-Extrudable Explosives and their Current Status*, Lawrence Livermore National Laboratory, UCRL-JC-103244 (1990).
3. J. F. Carley and E. von Holtz, "Flow of RF-08-FK high-energy paste in a capillary rheometer", J. Rheol., **41**, 473 (1997).
4. R.J. Farris, Trans. Soc. Rheol., **12**, 281 (1968).
5. D. M. Hoffman, C. M. Walkup, L. Spellman, W. C. Tao, and C. M. Tarver, "Transferable Insensitive Explosive (TIE)", Lawrence Livermore National Laboratory, UCRL-JC-117245 (1995).
6. L.E. Fried, *Cheetah 1.0, User's Manual*, UCRL-MA-117541, Lawrence Livermore National Laboratory, Livermore, CA..(1994)
7. S.H. Goods, T.J. Shepodd, B.E. Mills and P. Foster, *A Materials Compatibility Study in FM-1, a Liquid Component of a Paste Extrudable Exp[losive, RX-08-FK.* Sandia National Laboratory, Livermore, CA, SAND93-8237 UC-704, (1993).
8. T. N. Hale and J. R. Holden, Navy Explosive Handbook, NSWC MP 88-116 Naval Surface Weapons Center, Dahlgren, VA, October 1988.
9. A.M. Mellor, T.L. Boggs, J. Covino, C.W. Dickenson, D. Dreitzler, L.B. Thorn, R.B. Frey, P.W. Gibson, W.E. Roe, M. Kirshenbaum and D.M. Mann, Prog. Energy Combust. Sci., **14**, 213, (1988).
10. J. F. Carley, Rheology, in Introduction to Polymer Science and Technology (H. S. Kaufman and J. J. Falcetta ,eds) John Wiley and Sons (New York) 1977 pp. 425-455.
11. N Beckedahl, J Research NBS, **42**, 145 (1949).

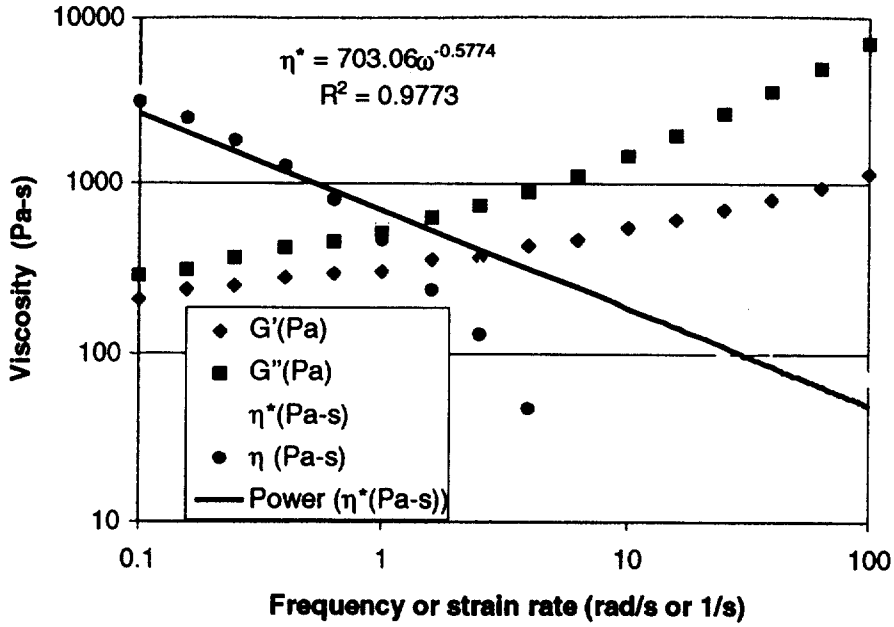


Figure 1. Dynamic viscosity and steady shear viscosity measurements of RX-08-HD can be fitted to a power law relationship over a short range of rates. Steady shear viscosity deviates from the fit near 1 sec^{-1}.

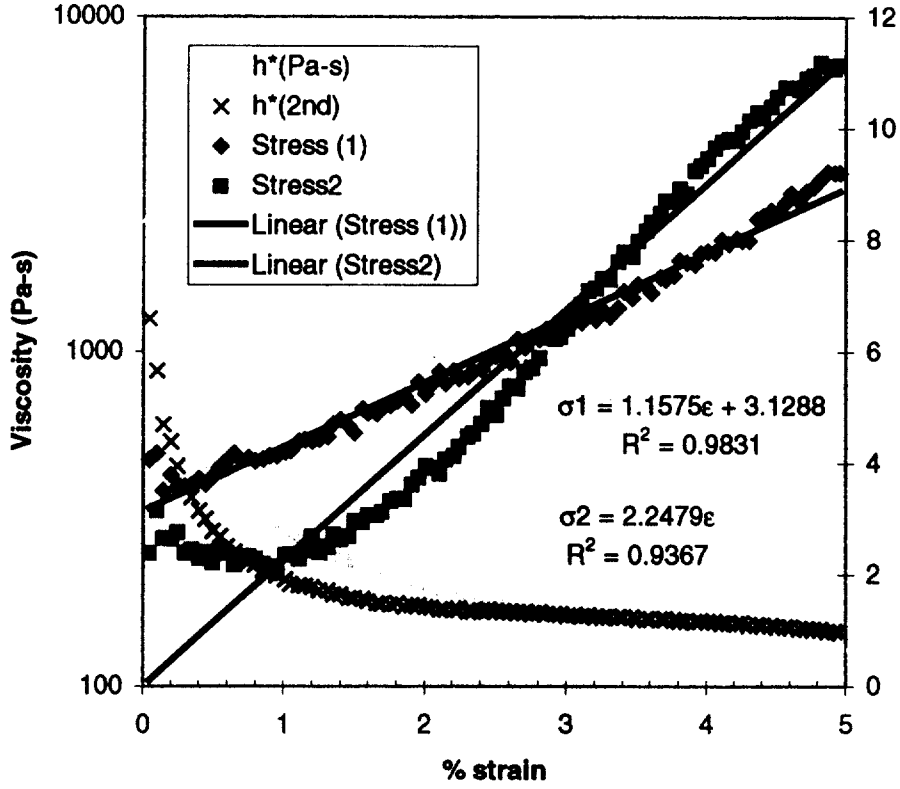


Figure 2. Dynamic viscosity and apparent stress as functions of strain amplitude show very mild thixotropic behavior in RX-08-HD.

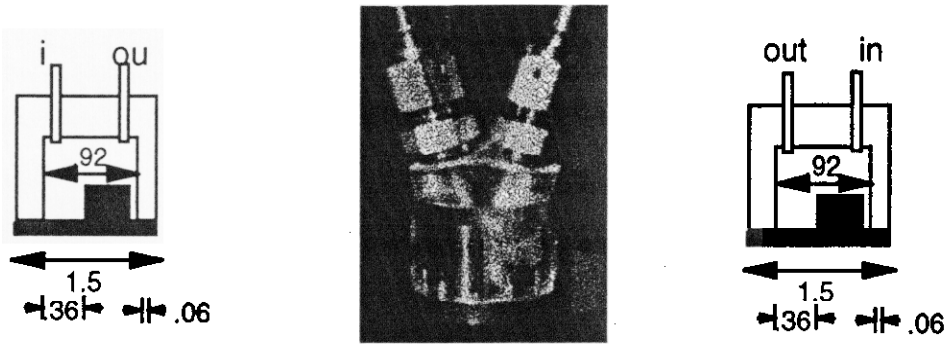


Figure 3. Alternate loading configurations of test fixture and beginning typical load.

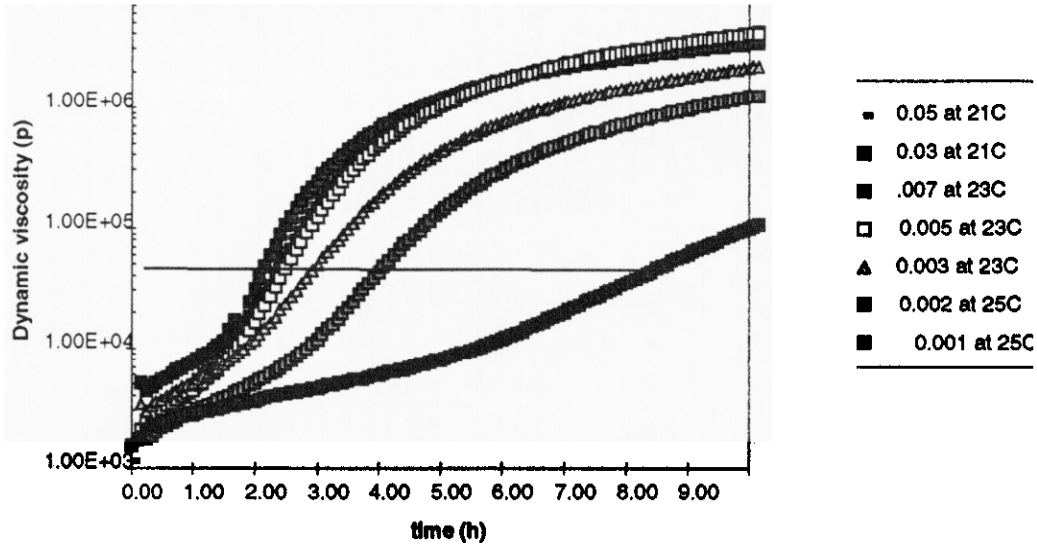


Figure 4. Cure characteristics of RX-08-HD as a function of T-131 catalyst content show that above 70-ppm minimal increase in cure is observed.

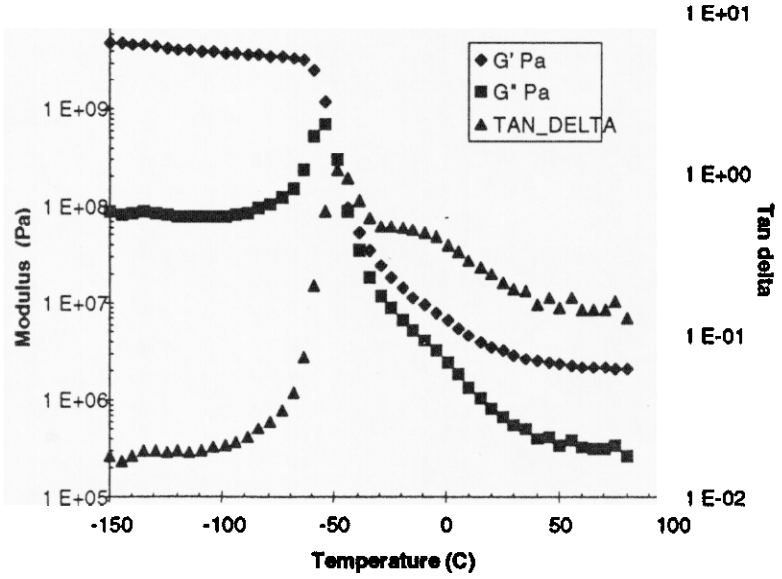


Figure 5. Dynamic mechanical shear and loss moduli of RX-08-HD as a function of temperature show vitrification at –40°C and crystallization of TMETN near 0°C.

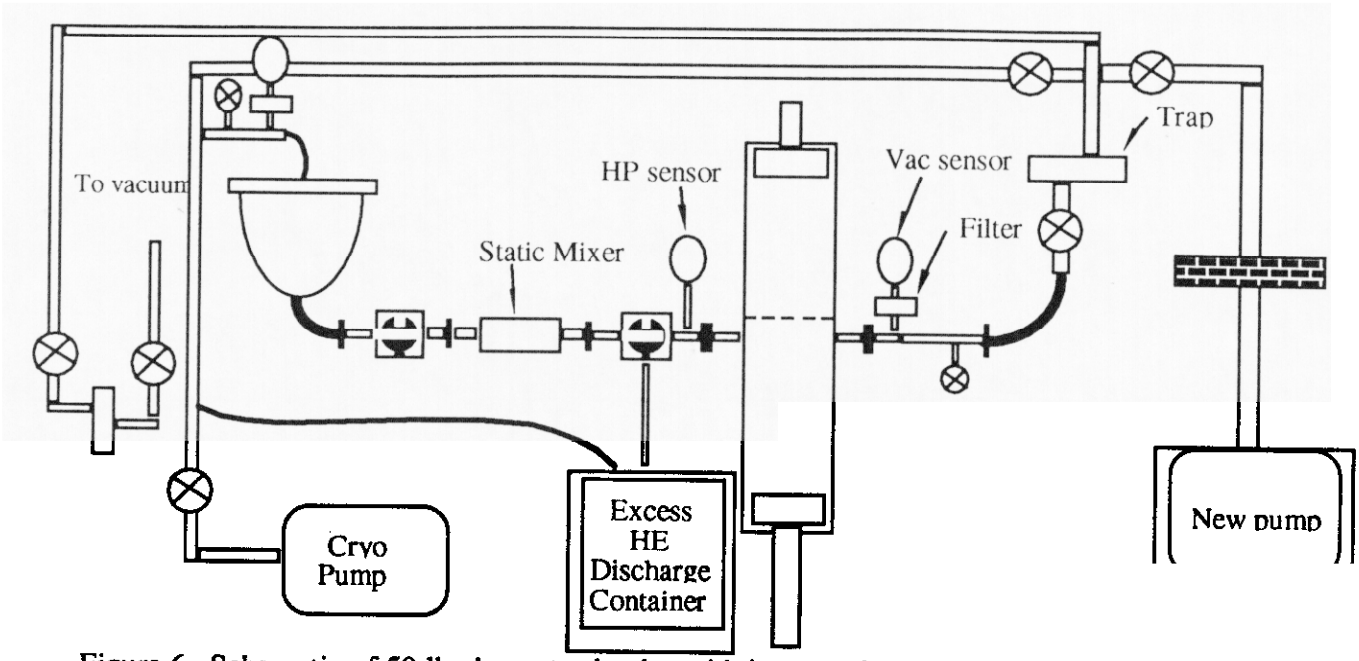


Figure 6. Schematic of 50 lb. deaerator loader with improved sensors and vacuum system.

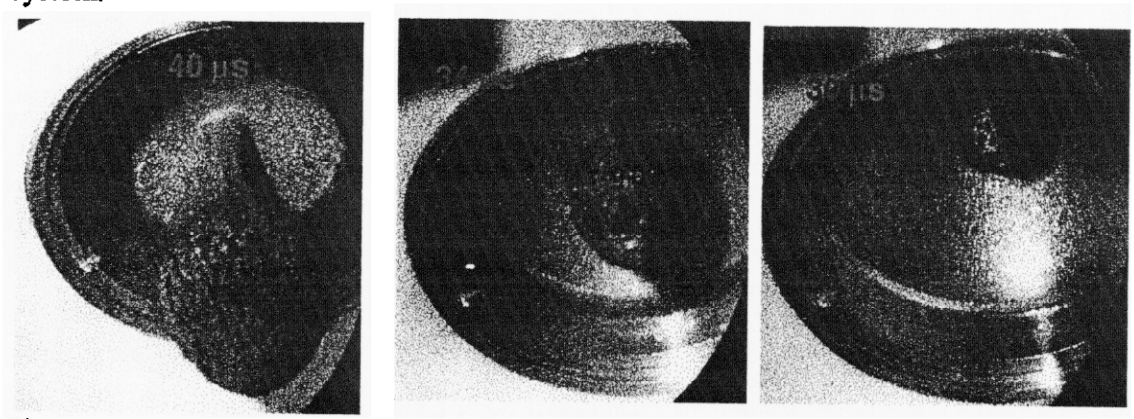


Figure 7. Shaped charge firing with RX-08-HD 40 ms after detonation shows nicely developed jet.

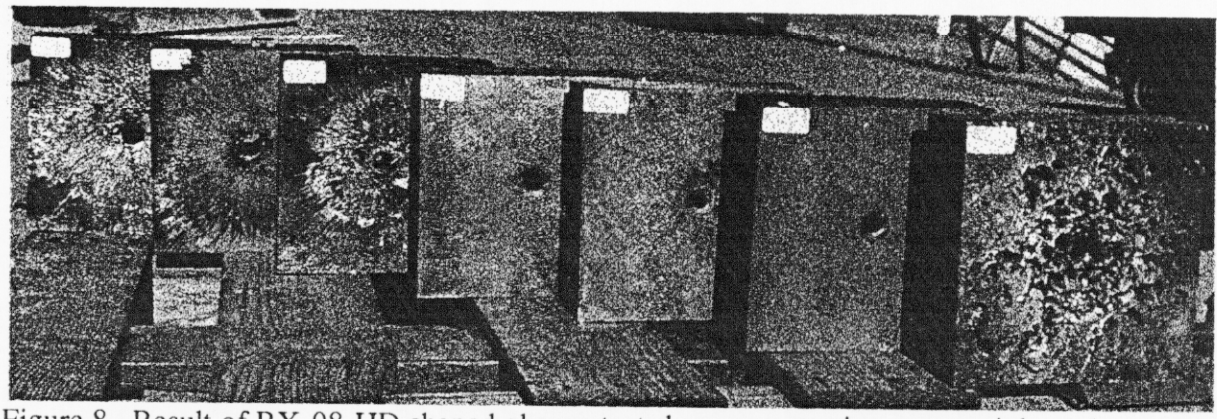


Figure 8. Result of RX-08-HD shaped charge test shows penetration was straight and uniform.

Technical Information Department • **Lawrence Livermore National Laboratory**
University of California • Livermore, California 94551