U.S. Army Research, Development and Engineering Command

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Less Sensitive Combined Effects Explosives

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- *ARDEC*
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Overview

- Background
  - Why Si
- Development tests
- Optimization- DOE
- Testing Results

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Background

- **Aluminum was studied in pressed combined effects explosives such as PAX-29, PAX-30 and PAX-42. These formulations exhibit metal pushing capabilities equal to or greater than LX-14 and provide enhanced blast.**

- **Performance was optimized for PAX30 as a function of aluminum particle size and amount of solids/binder.**

- ***The formulations do not pass the full suite of IM tests and therefore require reformulation or alternative fuels for desensitization.***

Test	# of Tests	Reaction				
		PAX-30	PAX-42	LX-14	PAX 3	N9 [1]
Bullet Impact	2	III	IV	IV	V	IV
Frag Impact	2	III	III	IV	V	N/A
FCO	2	IV	I, III	IV, V	V	
SCO	2	N/A	III, V	III, V	III/IV	IV

[1] S. Collignon. "IMAD HE Project – Evaluation of Candidate Shaped Charge Explosive". NSWCDD TR-94/158.

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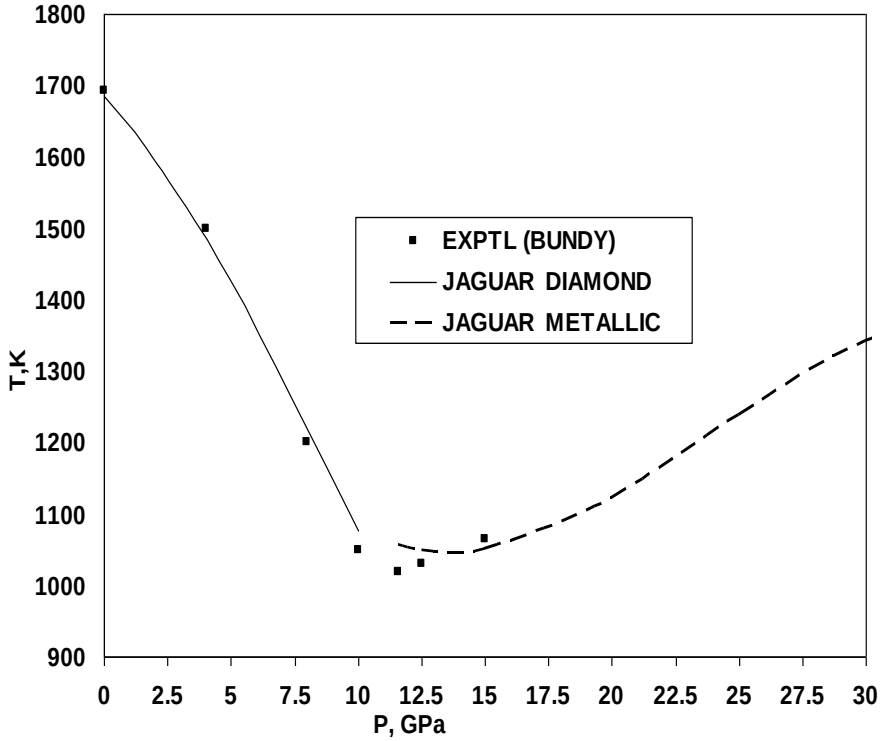
Background Continued



Silicon m.p. decreases with higher pressure

Formulation	Container	# shots	KE	KP	E
Minol	1" pipe	9	2	4	3
	3" x 3" x 3" box	3	2	1	
	½ pint paint can	3	3		
	Unconfined	3	3		
Silicominol	1" pipe	2	2		
	3" x 3" x 3" box	3	3		

KE = no reaction, KP = slight burn, E = explosion/deflagration,
From "Sensitivity of Explosives to Projectile Impact", OSRD 3156, 1944.

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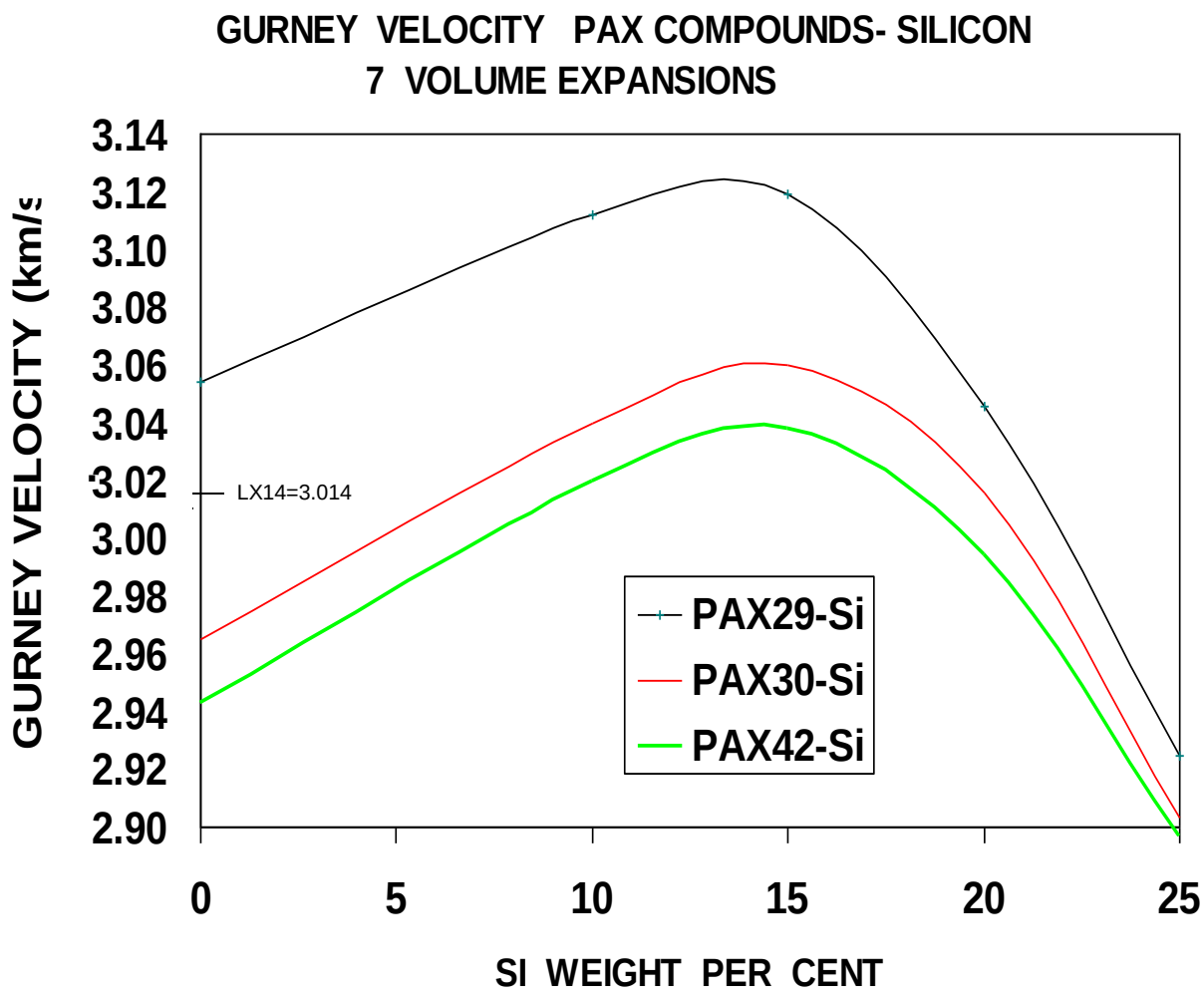
JAGUAR MODELING



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Goal

- Develop a replacement for aluminum in combined effects explosives with the goal to desensitize formulations without decreasing performance in metal pushing (Gurney energy) and blast.

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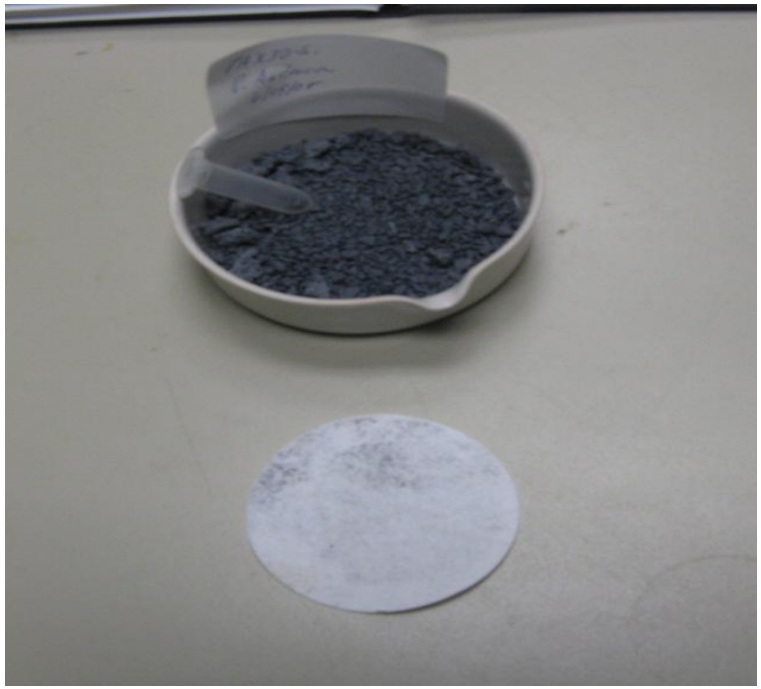
Processing Challenge

The hydrophilic nature of the SiO2 surface of the metal inhibits slurry processing.

This challenge was overcome by an amino-silane pre-treatment of the silicon.



Dent-Rate Performance

Shot Description	Type	Size	CJ Pressure, GPa	Detonation Velocity (km/sec)
1.44” dia confined	PAX-30	Al	30.5 ± 0.1	7.98 ± 0.05
	PAX-49	med Si	30.0 ± 0.2	7.68 ± 0.10
	PAX-49	small Si	29.0 ± 0.1	7.69 ± 0.01
	PAX-50	small Si	29.5	7.65
0.75” dia unconfined	PAX-49	small Si	26.7± 0.2	8.11 ± 0.08
	PAX-50	small Si	26.6 ± 0.0	7.90 ± 0.05

3 shots, all pellets >98% TMD

Si reaction – 7.87 km/s, Si inert – 8.14 km/s; Si therefore is most likely not reacting during unconfined detonation

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Gurney Energies

Explosive	Gurney Energies	
	V/V0 = 2	V/V0 = 7
LX-14	2.47 ± 0.1	3.01 ± 0.09
PBXN-9	Na	2.84
PAX30	2.42 ± 0.02	3.03 ± 0.04
PAX49	2.26 ± 0.07	2.87 ± 0.06

From cylinder expansion with 1 inch copper tubes

Detonation Calorimetry

Formulation	Theoretical Detonation Energy, kcal/g, 100% metal reaction*	Theoretical Detonation Energy, kcal/g, 0% metal reaction	Experimental Detonation Energy, kcal/g	Estimated % Metal Reaction
PAX-30	1645	1105	1590 ± 2	90
LX-14	1313	--	1363 ± 7	--
PAX-49	1610	1103	1483 ± 5	75
PAX-49-Mod	1496	1170	1463 ± 3	90
PAX-50-Si	1614	1106	1472 ± 3	72
PAX-50-Mod	1549	1118	1466 ± 9	81

Silicon showed full reactivity upon reformulation.

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Formulation Change

Formulation	Si Size	% Binder	% Si	% HMX/RDX
Original	Small	0.08	0.15	0.77
PAX49 Mod	Small	↑	↓	↑
PAX50 Mod	Small	↑	↓	↑

Increase Nitramine to offset decreasing Si
Increase binder to increase Si reaction

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Shock Sensitivity

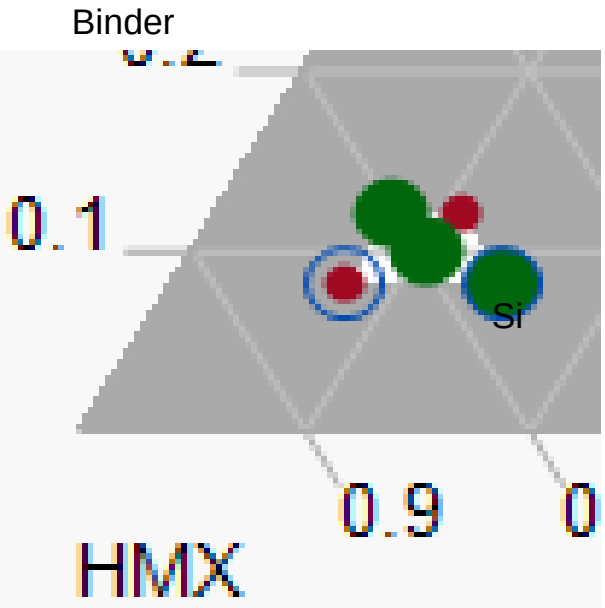
Formulation	NOL LSGT	
	Gap, cards (50%)	Pressure (kbars)
PAX-30[1]	160/161	33.8
PAX-49	163/165	32.3
PAX-50 Mod	170/180	28.1
LX-14[2,3]	199	21.0
PBXN-9[2,3]	166-201	20.5-31.4

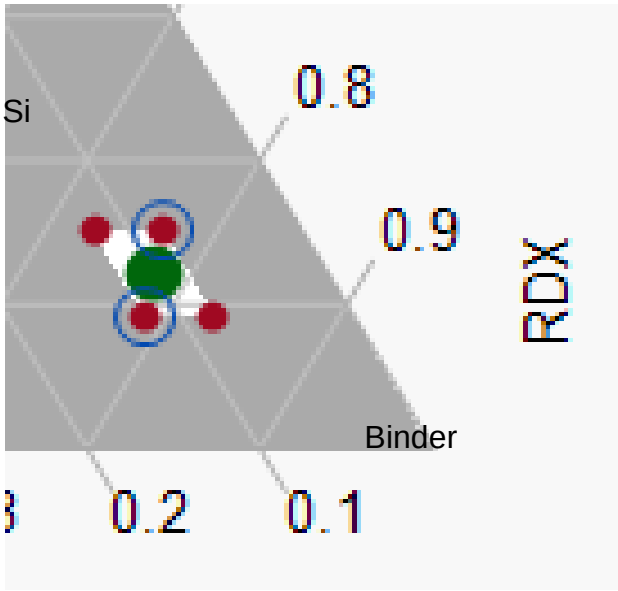
1 This mix utilized FEM ground CL5 HMX.

2 *NATO Manual of Data Requirements and Tests for the Qualification of Explosive Materials for Military Use*, Ed.2, 2003, US-42, STANAG 4488, Allied Ordnance Publication, STANAG 4488, (2003).

3 LLNL Explosives Reference Guide, Shock Initiation, High HMX

Technical Results - DOE





- A statistical design of experiments (DOE) is a set of experiments to test a response as a function of changed factors. It is *not* a trial and error approach.
- Results give statistically meaningful measures of main effects and secondary interactions arising from changes in mixture factors.
- Above ternary plots depict size of silicon used (color) and various mixture designs used in testing. Number of formulations for each nitramine was 7.

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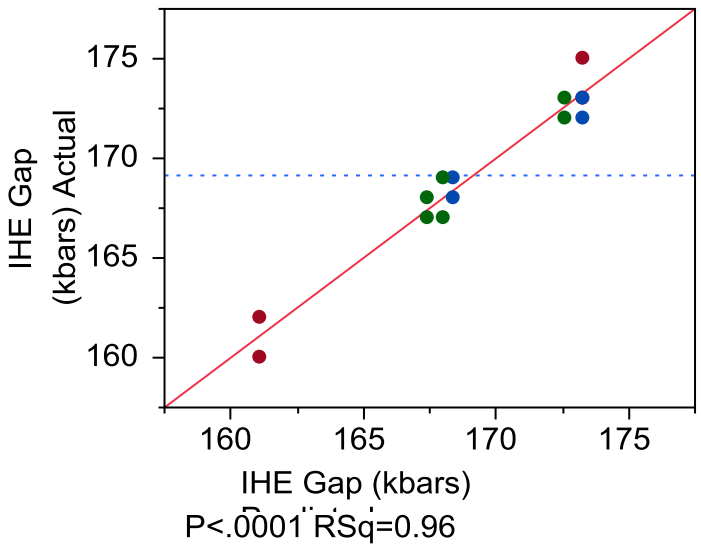
PAX-49 DOE



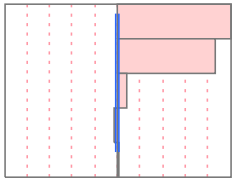
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	231.38029	57.8451	50.3780
Error	9	10.33400	1.1482	Prob > F
C. Total	13	241.71429		<.0001 *

Tested against reduced model:

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
(Si-0.08)/0.07	172.59046	0.679894	253.85	<.0001 *
(HMX-0.77)/0.07	177.48907	0.808707	219.47	<.0001 *
(Binder-0.08)/0.07	136.79637	6.450452	21.21	<.0001 *
Si size*Si size	-4.219682	0.698933	-6.04	0.0002 *
Binder*Binder	40.343672	11.64161	3.47	0.0071 *



- ***Squared silicon size term is real in this model.*** Physics of the shock initiation seem to be somewhat dependent on silicon size or surface area.
- Model is valid and usable but desire to augment design at the low shock sensitivity region (2 more runs).

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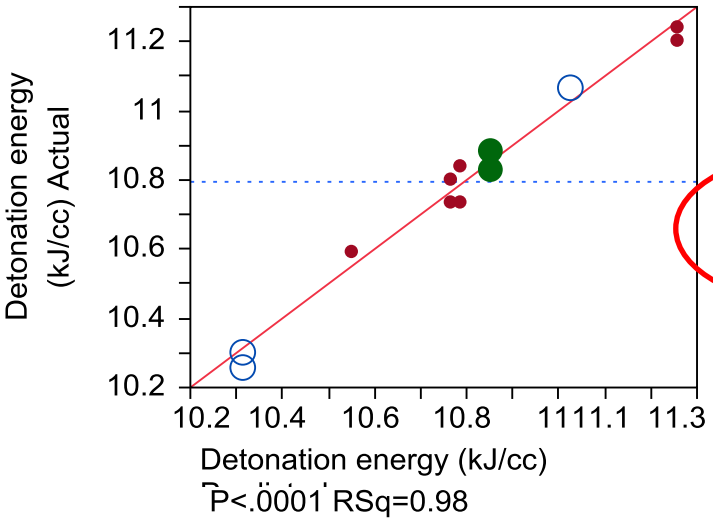
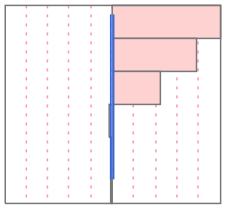
PAX-50 - DOE



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
(RDX-0.73)/0.1	10.779242	0.050071	215.28	<.0001 *
(Si-0.09)/0.1	11.602217	0.068526	169.31	<.0001 *
(Binder-0.08)/0.1	10.23767	0.104944	97.55	<.0001 *
Si Size(12,50)	-0.116862	0.018925	-6.18	0.0003 *
Binder*Si	-1.07016	0.315416	-3.39	0.0095 *
Si Size*Si Size	-0.129388	0.042317	-3.06	0.0156 *



Analysis of Variance

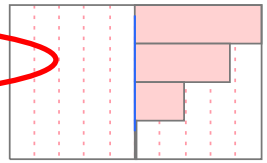
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	1.1275673	0.225513	78.7071
Error	8	0.0229218	0.002865	Prob > F
C. Total	13	1.1504891		<.0001 *

Tested against reduced model:

Results indicate binder an important factor in obtaining early silicon oxidation

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
(RDX-0.73)/0.1	173.93478	0.450858	385.79	<.0001 *
(Si-0.09)/0.1	161.61594	0.554117	291.66	<.0001 *
(Binder-0.08)/0.1	172.41304	1.141071	151.10	<.0001 *
Si Size(12,50)	1.7391304	0.305607	5.69	0.0005 *

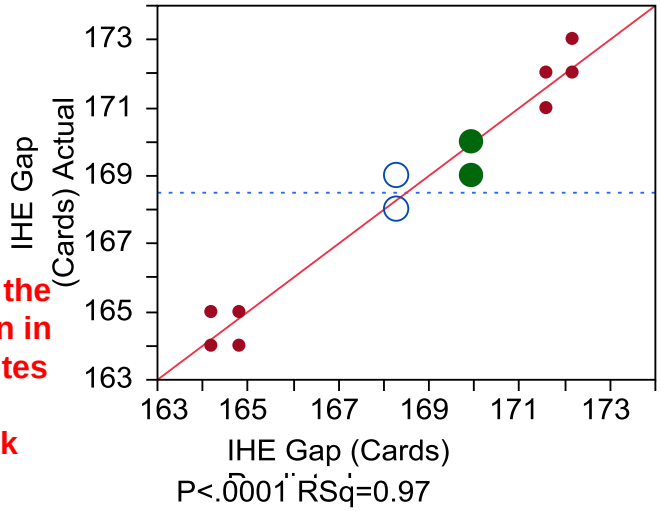


Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	114.95652	38.3188	75.8136
Error	8	4.04348	0.5054	Prob > F
C. Total	11	119.00000		<.0001 *

Tested against reduced model:

Results indicate the amount of silicon in mixture contributes significantly to changes in shock sensitivity



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3 LLNL Explosives Reference Guide, Shock Initiation, High HMX

IM Testing

Explosive	BI	SCO	FI
PAX30	III	NA	III[2]
PAX49 Mod	IV	III, V	III[2]
PAX42	IV	III, V	I[1]
PAX50 Optimized	IV	I	I[1]

3.2” Generic SCJ fixture
BI – 50 caliber bullet at 2789 ±66 ft/s good!
SCO – V reaction when back plate came off
FI –[1] 8300 fps; [2] 6000 fps; Hardness of Si?

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Questions?