U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – ARMAMENTS CENTER

Explosive Characterization for Improved Impact Response

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UNCLASSIFIED

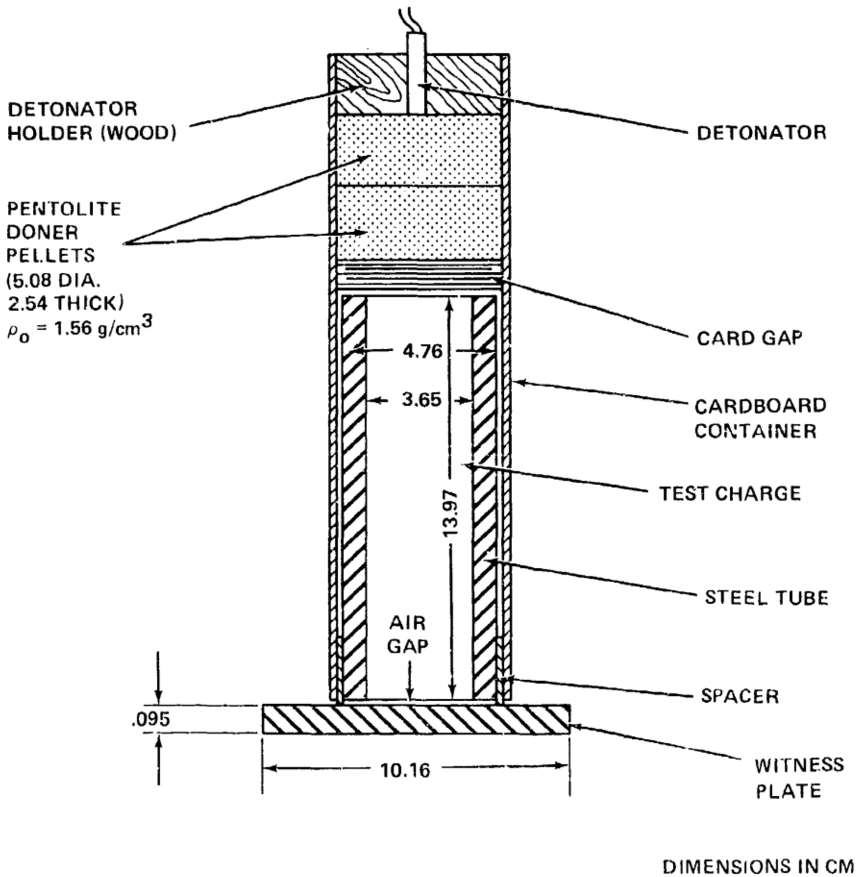
OVERVIEW

- Characterizing HE impact sensitivity
- Large Scale Gap Test (LSGT)
- NATO IM Fragment Impact (FI) testing
- Baseline Anti Armor warhead FI response
- Fragment Impact mitigation
- FEM Technology
- High rate continuum modeling methodology and predictions
- Experimental results
- Summary and conclusions

CHARACTERIZING HE IMPACT SENSITIVITY

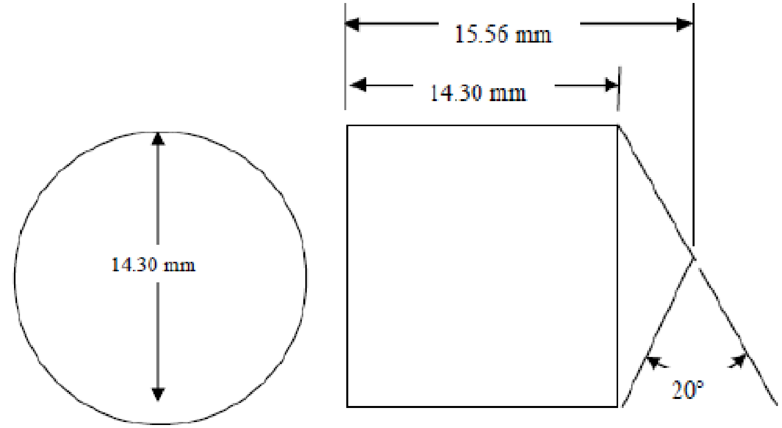
- Explosive shock sensitivity is generally characterized using large scale gap tests (LSGT)
- Small Scale Fragment Attack (SSFA) testing has recently been explored to address potential deficiencies in LSGT test
- Recent study presented engineering correlations of LSGT, Held's criteria, critical diameter and percent Theoretical Mazimum Density (%TMD)
- Fragment Impact (FI) testing characterizes the explosive response within a munition configuration
  - Reaction types range from Type I (detonation) to Type V (burn) and Type VI (no reaction)
  - LSGT and FI tests have unique phenomenon, as a result reduced card gap values may not translate into improved FI response
  - Additionally there are challenges with FI test repeatability

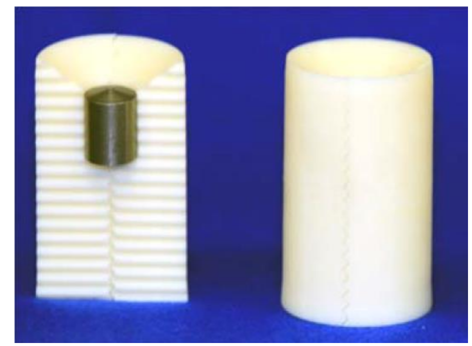
LARGE SCALE GAP TEST (LSGT)

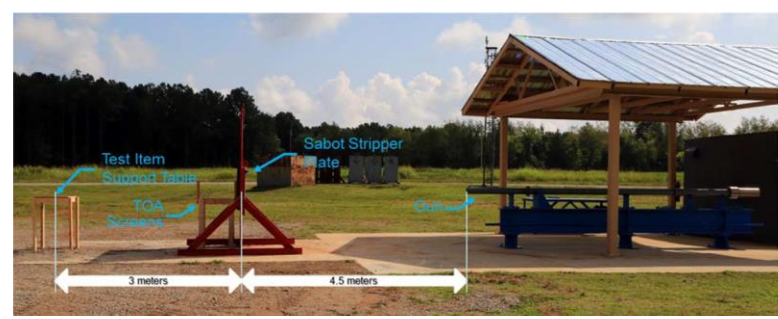


NATO IM FRAGMENT IMPACT (FI) TESTING

- NATO standard FI test (STANAG 4496) [1]
  - 14.3mm diameter, 18.6g, L/D~1, 160° conical nosed fragment
  - Mild steel, Brinell hardness <270
  - 2530±90 m/s impact velocity
  - Aimpoints: center of largest presented area of HE or most shock sensitive location
- Smooth bore 40mm powder gun often used in the U.S. [2]
  - Commercially available, used by various test facilities
  - Powder charge adjusted to obtain correct velocity
  - Replaceable wear section
  - Plastic sabot machined to fit
- Variability issues [2]





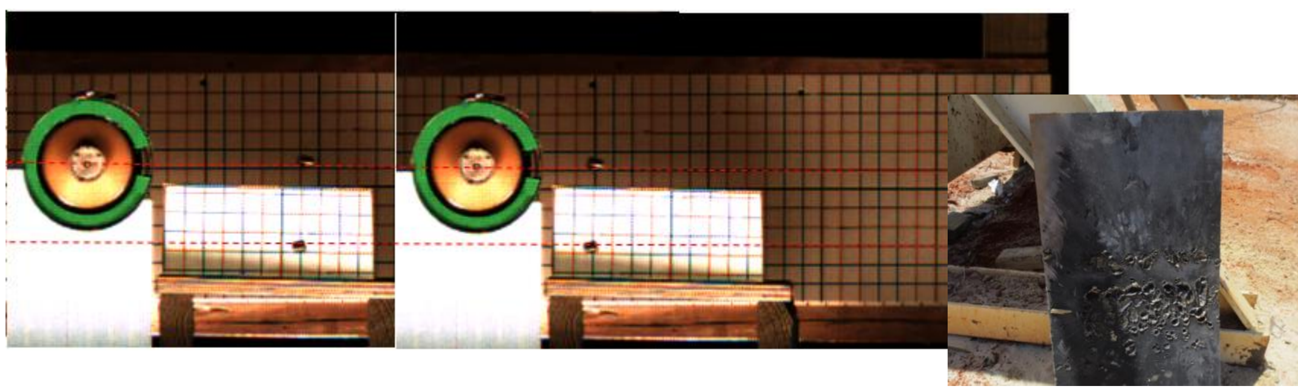


BASELINE AAW FI RESPONSE

•Anti-Armor Warheads with shaped charge (SC) or explosively formed penetrator (EPF), commonly use high energy, metal pushing energetic formulations (such as PBXN-9 and LX-14), react violently to FI (2530±90 m/s)

Logistical FI Test

Warhead A FI Test (Series 1)



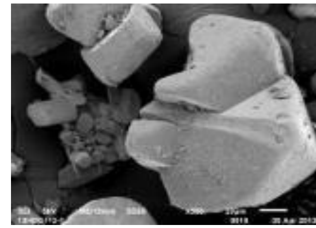
FRAGMENT IMPACT MITIGATION

- Fragment Impact Mitigation Technologies:
  - Utilize legacy formulations with improved sensitivity characteristics:
    - ❖PBXN-9 and LX-14 with FEM HMX
    - ❖FEM HMX LSGT is 30 cards less than std LX-14
  - PIMS technology:
    - ❖Remove initial impact shock
    - ❖Provide sufficient fragment velocity reduction, breakup and dispersion resulting in a weaker threat

FEM TECHNOLOGY

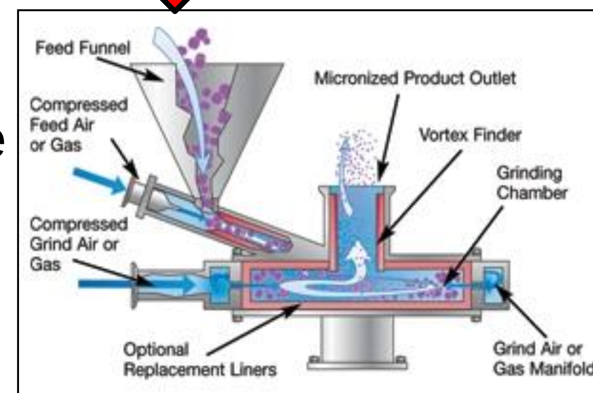
Traditional mechanical size reduction technology

- Particles mechanically milled
- Rough, irregular shapes of crystals



Simple technical innovation

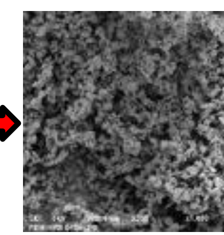
- Compressed air employed to move explosive in mill chamber
- Particle-to-particle impact



No moving parts with energetic processing

- No sensitized handling of explosives
- Removal of “pinch points,” extended friction
- No collection of hazardous explosive dust

BAE SYSTEMS

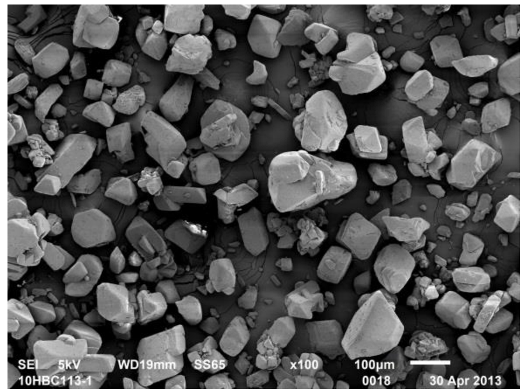


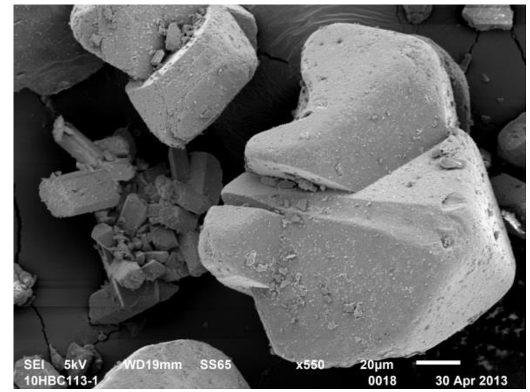
FEMHMX INPUT MATERIAL

- Program incorporated one FEMHMX batch material for experimentation

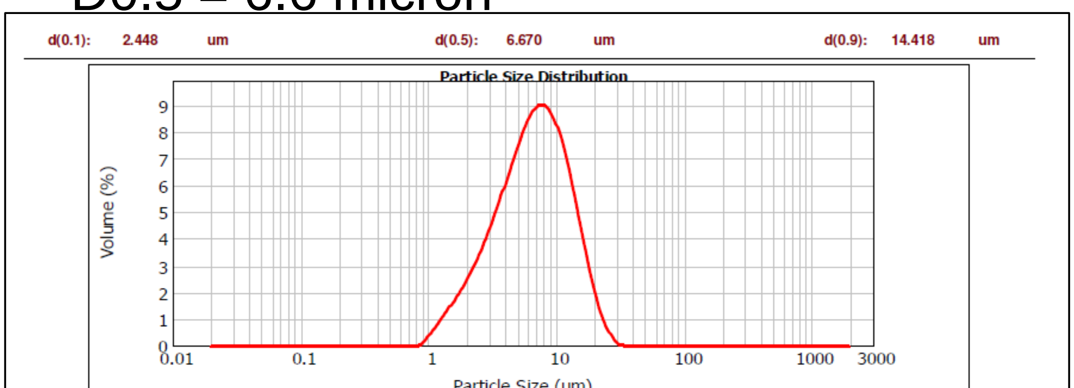
BAE SYSTEMS

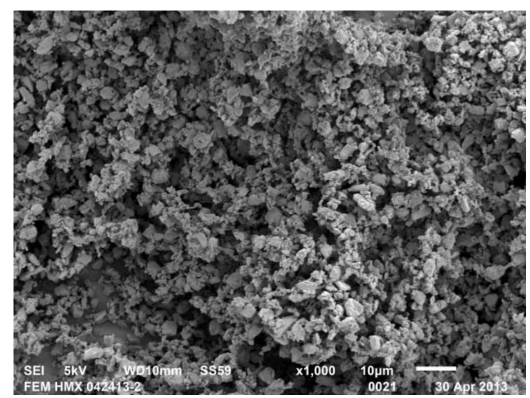
- HMX Class 1 milled to FEM requirements
  - Feed Rate: 5lbs/hr
  - Feed Air: 80 psi
  - Grind Air 100 psi





- FEMHMX
  - D0.5 = 6.6 micron



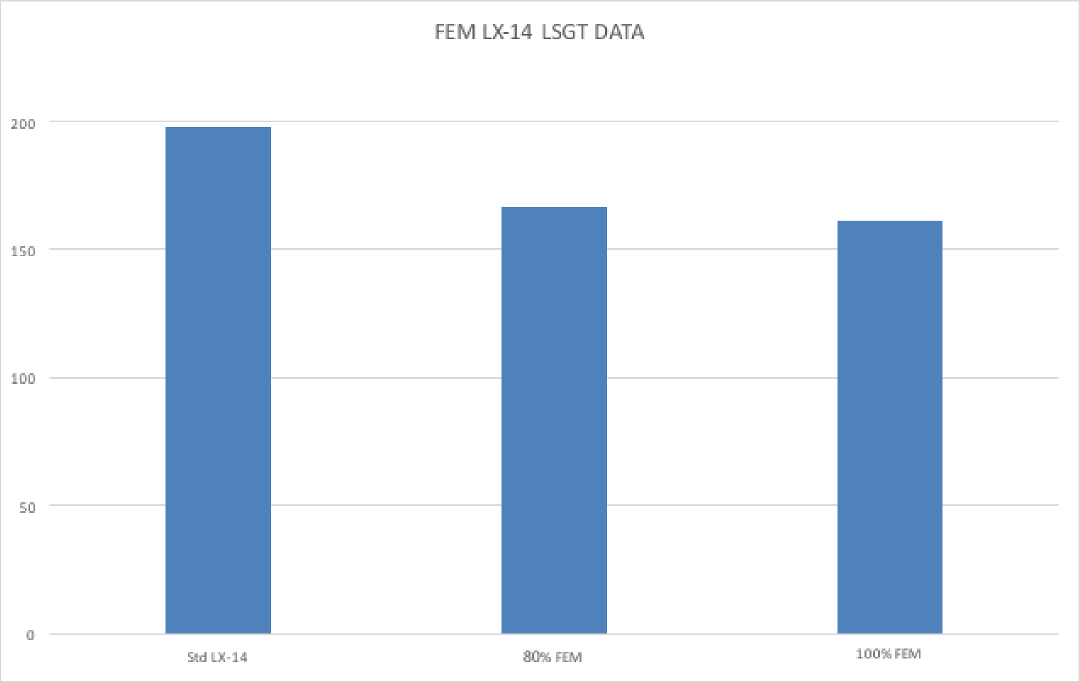


FEM LX-14

			Density
	% FEM	Cards	g/cc
LX-14	Std LX-14	198	1.80
	80% FEM	166.5	1.81
	100% FEM	161.5	1.80

		Cards
PBXN-9	Control	186.5
	45% FEM	184.5
	75% FEM	186.5
	100% FEM	156.0

BAE SYSTEMS



80% FEM LX-14 Selected for better consolidation and diminishing returns on card gap value

LSGT RESULTS

HE	FI Series	HE Pressed Density [g/cc]	Card Gap
Standard PBXN-9	1	1.73	175
Standard PBXN-9	2	1.73	169
Standard PBXN-9	3	1.73	179
Standard LX-14	--	--	236
LX-14 with 80% FEM HMX	4	1.81	166.5
LX-14 with 80% FEM HMX	--	1.80	177

Standard PBXN-9 and LX-14 with 80% FEM HMX have similar card gap value

FI TEST RESULTS

Series	Test Condition	Explosive	Reaction Type
Baseline	Warhead A - Logistical	PBXN-9	I
1	Warhead A	PBXN-9	(I)
1	Warhead B	PBXN-9	(III)
1	Warhead B	PBXN-9	(III)
2	Surrogate Warhead A – steel 1	PBXN-9	(IV)
2	Surrogate Warhead A – steel 1	PBXN-9	(V)
2	Surrogate Warhead A – steel 1	PBXN-9	(V)
2	Surrogate Warhead A – steel 2	PBXN-9	(IV)
2	Surrogate Warhead A – steel 2	PBXN-9	(IV)
2	Surrogate Warhead A – steel 2	PBXN-9	(V)
3	Warhead A - No Liner	PBXN-9	(IV)
3	Warhead A - No Liner	PBXN-9	(IV)
3	Warhead A - Liner 1	PBXN-9	(IV)
3	Warhead A - Liner 1	PBXN-9	(V)
3	Warhead A - Liner 1	PBXN-9	(IV)
3	Warhead A - Liner 2	PBXN-9	(V)
3	Warhead A - Liner 2	PBXN-9	(IV)
4	Surrogate Warhead A – steel 1	80% FEM LX-14	(I)

PBXN-9 varied response in series 1 and 3 of similar configuration (Warhead A)

Standard LX-14 is notably more sensitive than PBXN-9 with a recorded card gap of 236

Utilizing 80% FEM HMX drops this value by 27%, with a mean of 171.5 cards

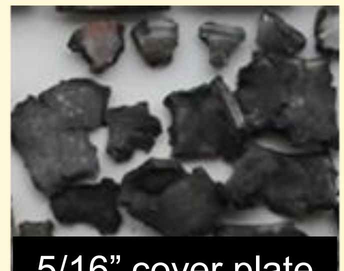
This is comparable to mean LSGT values for PBXN-9 of 174.3 cards

SSFA RESULTS

Material	Cover plate thickness [in.]				
	1/8	1/4	5/16	3/8	1/2
PBXN-9 - Lot A	I	IV	--	V	--
PBXN-9 - Lot B	I	IV	--	VI	--
LX-14	--	III	III	III	III
LX-14 (80% FEM)	--	III	--	IV	IV

Standard LX-14


¼” cover plate


5/16” cover plate


3/8” cover plate

80% FEM LX-14

¼” cover plate


3/8” cover plate

Standard PBXN-9


¼” cover plate


3/8” cover plate

FI RESULTS

- *Series 1 and baseline FI responses significantly more violent (Type I) when compared to those of similar configuration series 3 tests (Warhead A)*
    - *Potential lot-to-lot variability in the PBXN-9 material, which results in the varied response to impact stimulus. Lot-to-lot variability in impact response has been observed in prior tests using LX-14 [9, 10]*
    - *Uncertainty may be due to the difficulty of fragment flight control [6]*
- *Warhead A configuration appears to be more sensitive as compared to warhead B in FI*
- *Similar configuration FI test results of FEM LX-14 detonate, while those of PBXN-9 respond benignly, suggesting that FEM LX-14 should have a higher card gap value. However, PBXN-9 and 80% FEM LX-14 have similar card gap values*
    - *The mechanism is unclear, but contributing factors could include shear concentration in the considerably stiffer FEM LX-14 binder, which would be exacerbated by shock-front curvature in an FI test.*

SSFA RESULTS

- *SSFA results align more closely with FI data, and suggest greater impact sensitivity of 80% FEM LX-14 over PBXN-9*
  - *Differences in response likely due to binder material stiffness, total nitramine loading content, and crystal shear. FEM LX-14 contains smaller crystals that reduce average void size and response under adiabatic compression in the short duration, planar LSGT environment*
  - *Crystal size and binder stiffness can contrarily also explain the increased sensitivity under FI test, with shear concentration leading to initiation rather than void collapse.*
- *All standard LX-14 reactions were assessed as Type III, although increasing violence observed with increasing cover plate thickness*

SSFA RESULTS
(Cont'd)

- *Trends observed in the gap test experiments diverge from those observed in the impact tests.*
  - *Phenomenological models, such as the Hugh James criteria, predict initiation based on a set of threshold metrics [11, 12].*
  - *The James criteria is a hyperbolic relationship between a critical energy fluence and a critical specific energy term.*
  - *Gap tests approach the asymptote of the Energy Fluence with high amplitude, short duration shock events.*
  - *Impact tests approach the Specific Energy asymptote, with lot amplitude, long duration events that impart more particle velocity to the HE.*

CONCLUSION

- *Both LSGT and SSFA tests are useful screening tests for the prediction of full scale, system level FI reaction violence.*
  - *LSGT provides large body of historical data for comparison, is inexpensive and can be conducted at a number of facilities. Most applicable to prompt shock to detonation transition (SDT). Limited modeling capability*

- *Munitions FI response dependent upon additional factors, not captured by LSGT, such as fragment tile, yaw, miss distance, curvature, shear initiation and damage.*

- *Although SSFA lacks historical body of data, it provides an unquantified indication of shock, damage, and penetration phenomena as well as a gross, relatively inexpensive, qualitative assessment of a munition's response.*

CONCLUSION (Cont’d)

SSFA methodology is somewhat different from FI and care must be taken in interpreting the results. SSFA requires further study to gauge robustness for additional explosive systems

- *Additional testing with reproducible results (LSGT, SSFA, and FI) would provide statistically relevant data set with which to measure HE sensitivity.*
- *LSGT, SSFA and FI results serve as a body of evidence for explosive sensitivity*
- *The divergence of LSGT and FI experimental techniques is not altogether unexpected, as phenomenological models such as the Hugh James criteria treat initiability as a hyperbolic function of both short pulse, high amplitude (explosive, e.g., LSGT) events and longer acting, lower amplitude (impact, e.g., FI) events.*

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REFERENCES

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