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

Propellant Optimization

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DISTRIBUTION A

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Fouling Reduction

PROJECT BACKGROUND

BLUF: Direct impingement weapon systems are susceptible to bolt fouling due to unburnt propellant and other propellant additives cycling through the system during a firing event

- **Constituent quantities blended in the propellant will effect the amount of fouling imparted on the weapon system**
  - Inorganic constituents account for most fouling
- **Phase 1 - six (6) propellant formulations were conceptualized, produced, and loaded into M855A1 cartridges for testing.**
  - M4A1 weapon fouling tests conducted at Olin-Winchester
  - Chemical analyses conducted at ARL
  - Muzzle Flash testing conducted at BSO
- **Phase 2 – two (2) formulations were down-selected and further evaluated vs. the control propellant.**
  - Fouling and LAT testing at Olin-Winchester
  - Chemical analyses at ARL
  - Muzzle flash testing at ARDEC and ATC

PROPELLANT FORMULATIONS

Sample #	1	2	3	4	5	6	7 (Control)
De-coppering agent %	-	-	-	-	-	-	0.22
Standard Flash Suppressant (Surface) %	0.7	0.2	0.2	0.2	0.2	0.2	0.5
Alternate Flash Suppressant (Surface) %	-	0.4	-	0.6	-	-	-
Alternate Flash Suppressant (Pellet) %	-	-	0.4	-	0.6	-	-
Total Flash Suppressant %	0.7	1.0	1.0	1.4	1.4	0.2	0.5
Nitroglycerine %	12.88	12.97	12.8	12.87	12.73	10.21	13.32
Bulk Density (g/cc)	1.003	0.972	1.008	0.982	1.007	0.991	1.006

M4A1 FOULING TEST DOE

- **Phase 1**
  - Seven (7) M4A1 weapons were used to fire a total of 1,200 rounds of each propellant formulation (6 experimental and 1 control)
    - Each gun was broken in with 3600 rounds prior to DOE commencement
    - (7 Samples) x (7 Guns) x (1200 Rounds) = 58,800 rounds tested in DOE
    - Bolt assembly and bolt weights were measured at 600 round increments. Guns were cleaned after 1200 rounds before moving to the next sample.
    - Each gun started with a different sample number and indexed to account for gun history.
- **Phase 2**
  - Three (3) M4A1 weapons were used to fire a total of 2,400 rounds of each down-selected formulation (2 experimental and 1 control)
    - (3 Samples) x (3 guns) x (2400 Rounds) = 21,600 rounds tested
    - Tested and measured as above

BOLT FOULING DATA- PHASE 1

Phase 1 Fouling Data

	Propellant Formulation						
	1	2	3	4	5	6	7
Average Bolt Fouling Mass (g)	0.1471	0.2102	0.1458	0.1945	0.1635	0.1305	0.1726
Percent of Control	85%	122%	84%	113%	95%	76%	100%
Average Bolt Carrier Assembly Fouling Mass (g)	0.5631	0.7834	0.5559	0.7871	0.6985	0.4228	0.6079
Percent of Control	93%	129%	91%	129%	115%	70%	100%

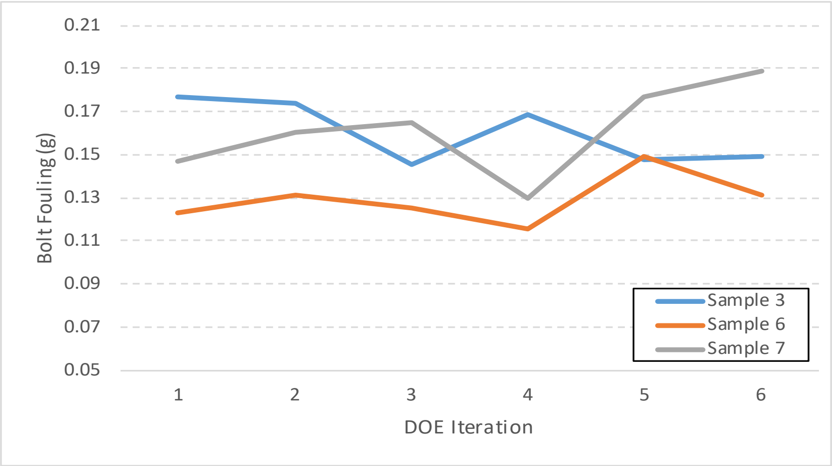
Phase 1 Down-Select Analysis

	Fouling Mass (Olin)		Fouling Composition (ARL)		Muzzle Flash Intensity (BSO)		
Sample	Bolt	Assembly	M4A1	Mann Barrel	Peak (cd)	Integrated (cd*s) x10^{-4}	Average Rank
1	3rd	3rd	5th	4th	5th	5th	4.2
2	7th	6th	4th	5th	7th	6th	5.8
3	2nd	2nd	2nd	2nd	3rd	4th	2.5
4	6th	7th	6th	3rd	6th	7th	5.8
5	4th	5th	7th	6th	1st	3rd	4.3
6	1st	1st	1st	1st	4th	1st	1.5
7 (Control)	5th	4th	3rd	7th	2nd	2nd	3.8

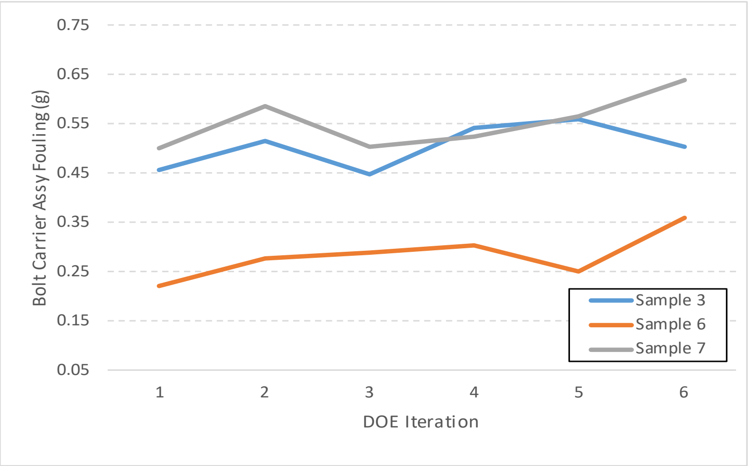
Phase 1 testing showed compelling results for improved fouling formulations, down selected to continue investigation of samples 3 and 6

BOLT FOULING DATA – PHASE 2

Bolt Fouling



Bolt Carrier Assembly Fouling



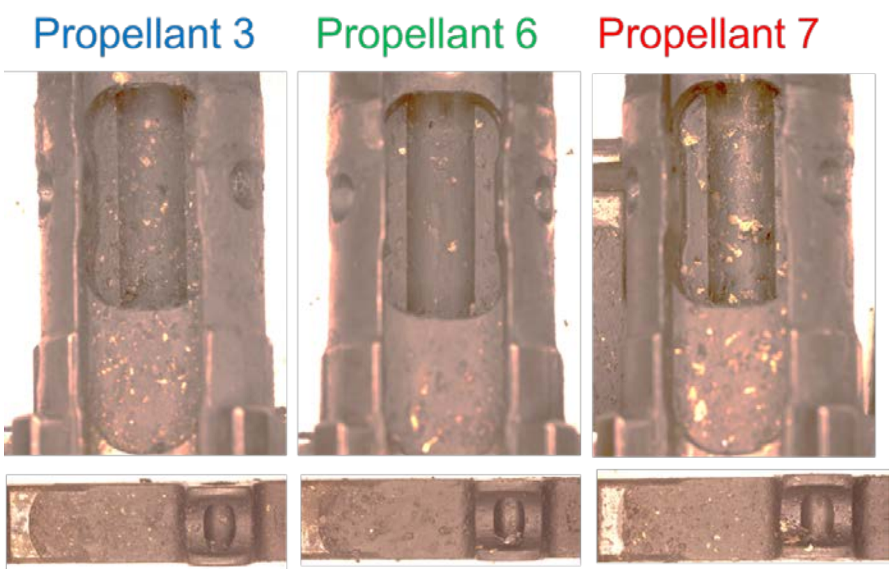
Phase 2 Fouling Data

	Propellant Formulation		
	3	**6**	**7**
Average Bolt Fouling Mass (g)	0.1605	0.1294	0.1614
Percent of Control	99%	80%	100%
Average Bolt Carrier Assembly Fouling Mass (g)	0.5044	0.2839	0.5531
Percent of Control	91%	51%	100%

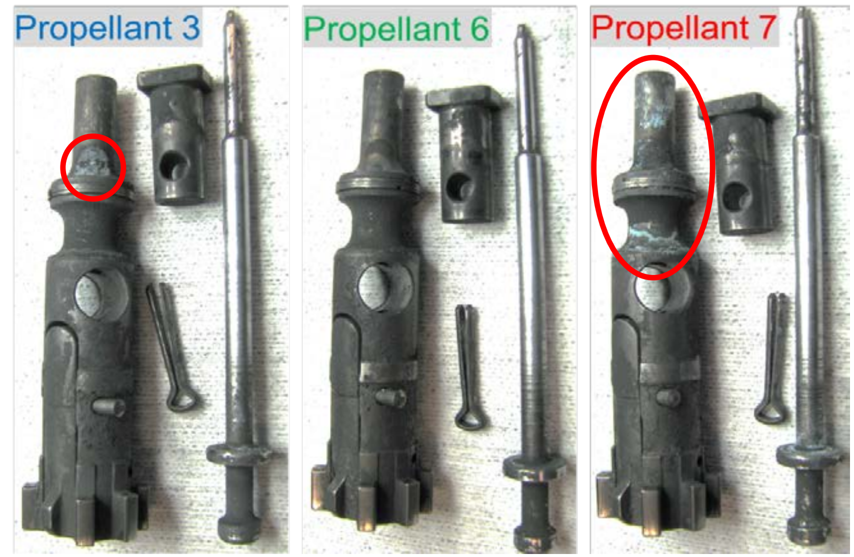
Sample 6 reduced bolt assembly fouling by 51% compared to the control

ARL – VISUAL OBSERVATIONS

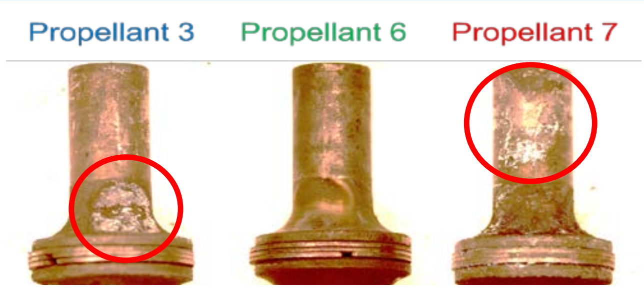
- **Dirty bolts observed under magnification, and under ambient lighting conditions**



Extractor shows very few brass shavings from sample 6. Less risk of failure to extract or eject.

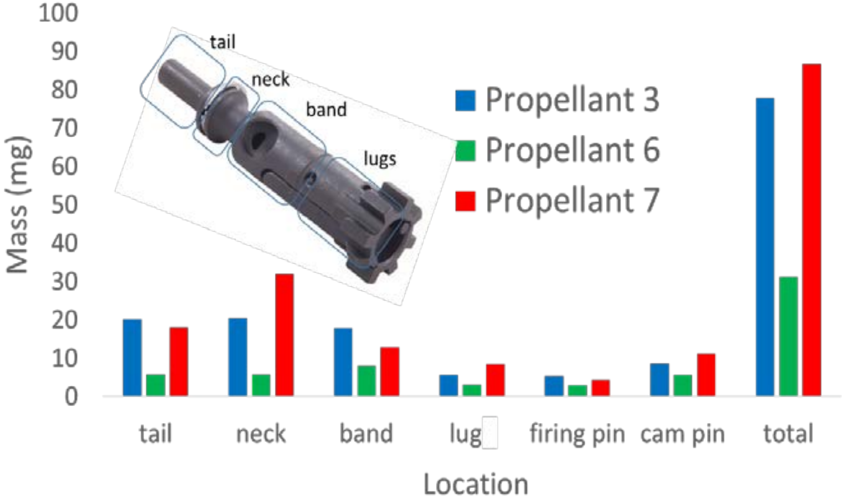


Basic Copper Carbonate (BCC) shown in excess on bolt tail for Sample 3 and 7. Most difficult residue to clean from bolts.

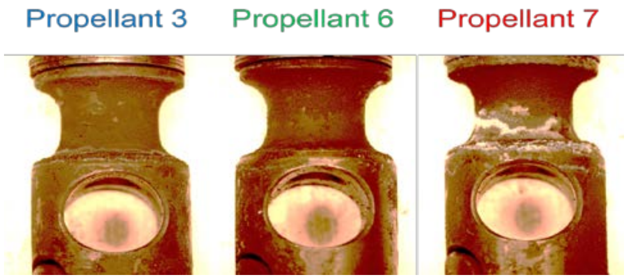


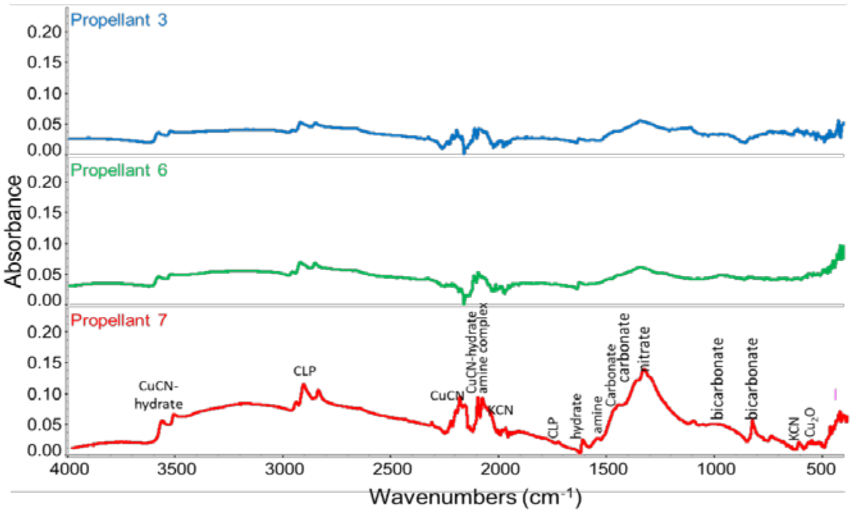
ARL ANALYSIS – BOLT AND ASSEMBLY

- **Quantitative and qualitative analyses were performed on dirty bolts which further confirmed conclusions from bolt weight analysis performed at Olin**
  - Residue was scraped from the dirty bolts and weighed by region
  - IR spectroscopy was performed on the residue to determine the chemical composition



Sample 6 is clearly superior in terms of fouling mass





Spectra of Sample 3 and 6 suggest "cleaner" residue compared to Control. Much less cyanide and carbonate/bicarbonate products.

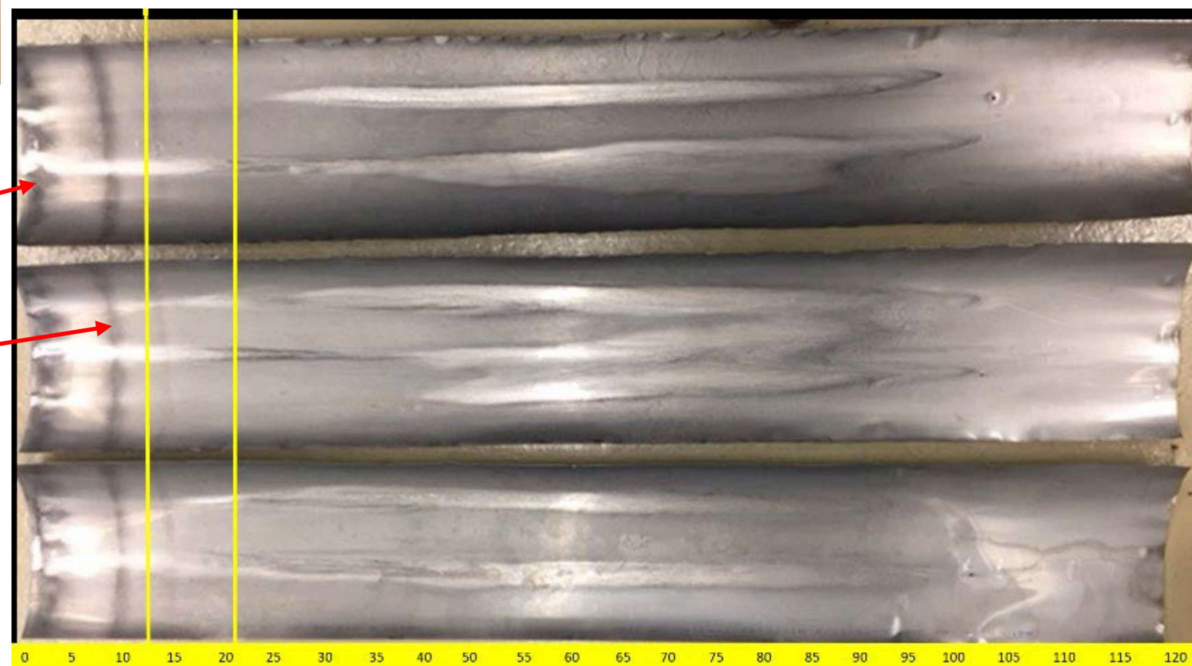
ARL MUZZLE "SHIM" TEST METHOD

- **Roll sheet metal shim into a tube and affix at the muzzle of the M4A1 weapon**
  - Fire 10 rounds of one sample type
  - Repeat with 3 shims for each sample type
- **Sheet metal is unrolled and observed visually both with and without magnification**
  - Impact points were counted at 12cm and 21cm from the muzzle within a random 4cm^2 area
  - Impacts were measured to estimate particle size
- **pH strips were used to determine alkalinity of the residue**

ARL MUZZLE "SHIM" SETUP

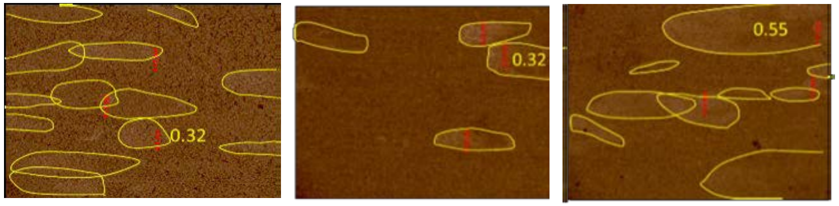
Primary flash signature

Secondary flash signature



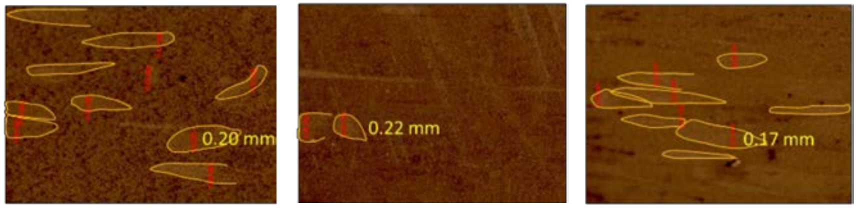
ARL MUZZLE "SHIM" IMPACT RESULTS

Impacts 12cm from muzzle

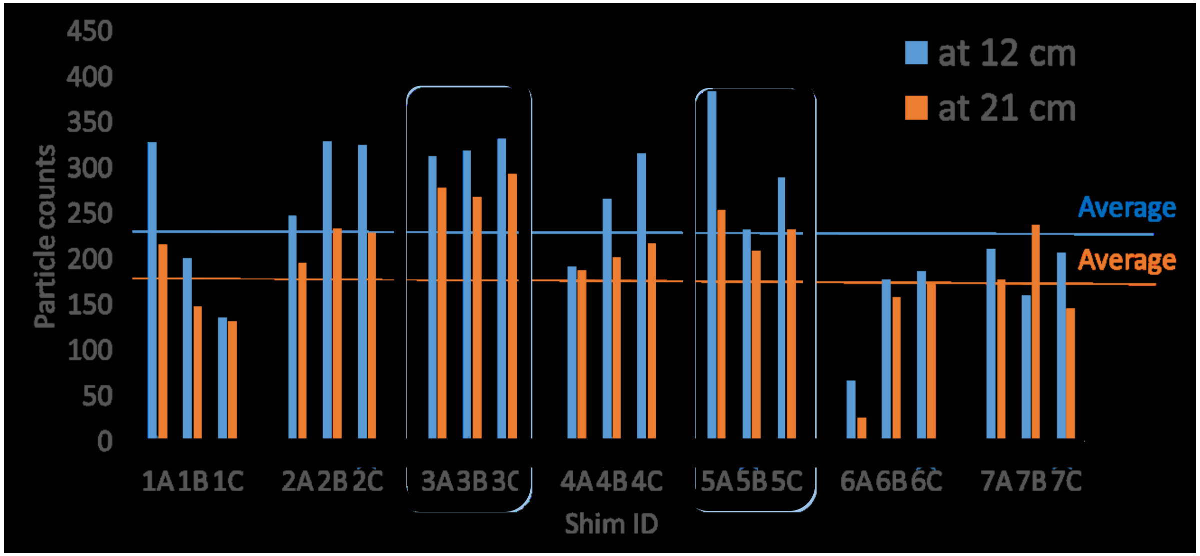


Sample 3 Sample 6 Sample 7

Impacts 21cm from muzzle



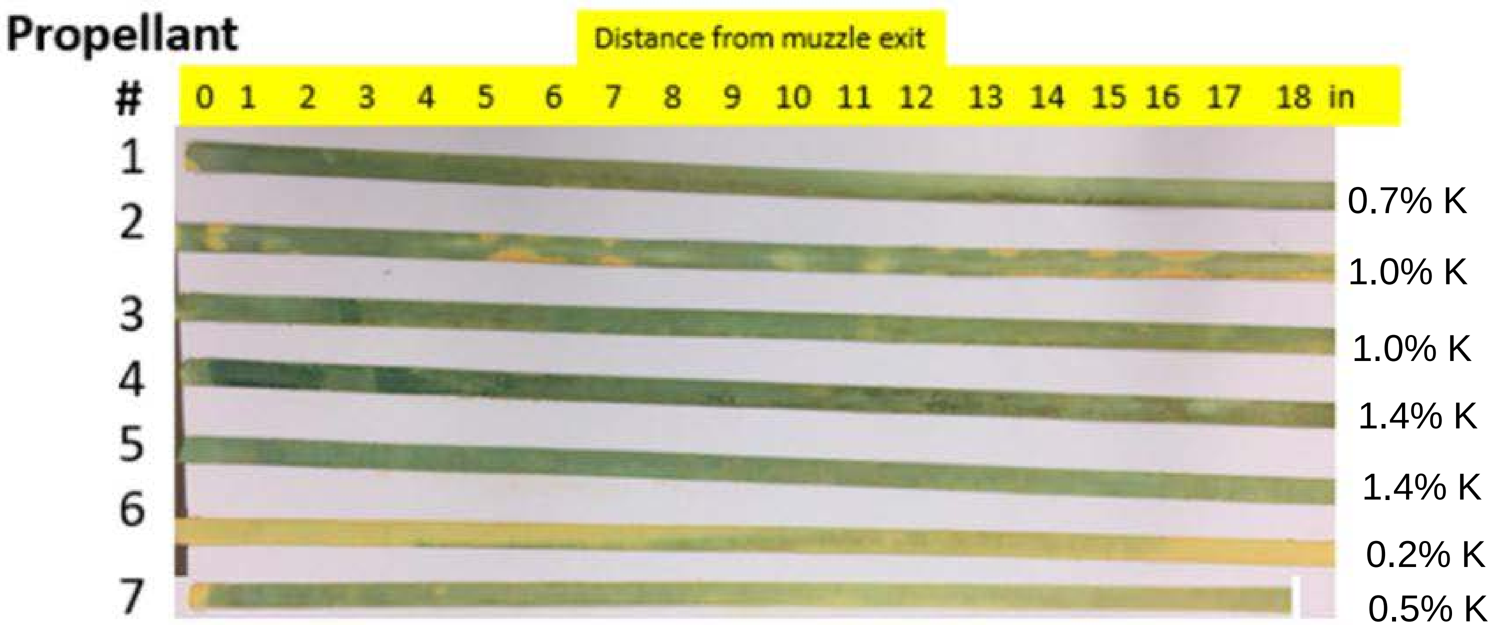
Sample 3 Sample 6 Sample 7



Reduced muzzle fouling would be an added benefit for silenced weapon systems

MUZZLE "SHIM" ALKALINITY TEST

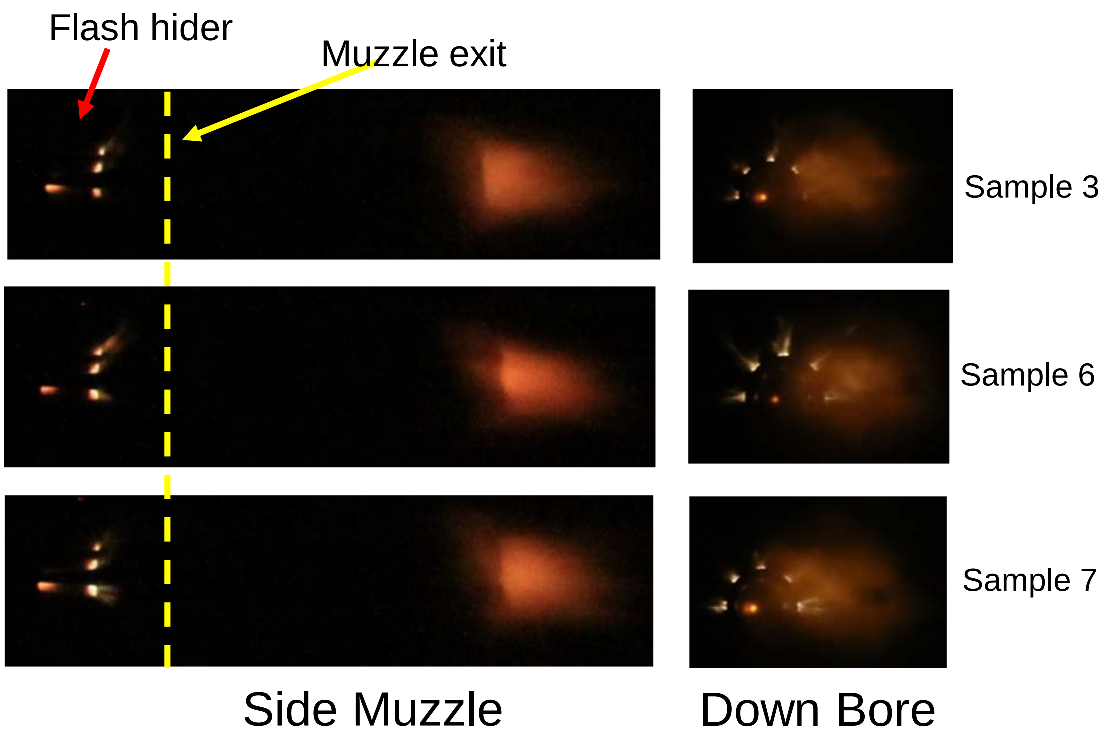
- **pH of ~7 (neutral) turns yellow. More alkaline Ph ~9 turns green**
  - Potassium based flash suppressants are highly alkaline

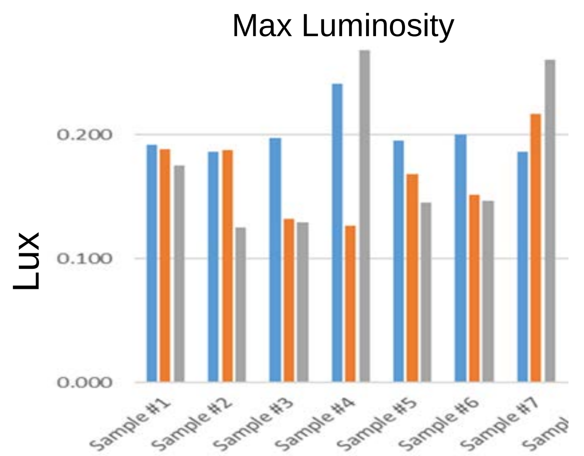


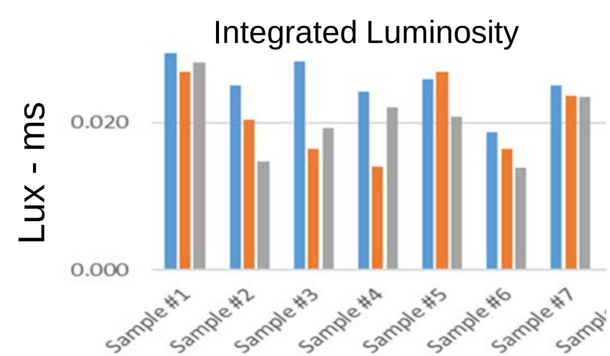
pH strips suggest alkaline products are expelled from all weapons, but less for Sample 6

MUZZLE FLASH TESTING

- **A study was performed to determine if reduction in flash suppressant would significantly impact muzzle flash**
  - Intensity of muzzle flash was observed using a photo optic sensor
  - Open shutter photography was used to compare muzzle flash visually







No significant difference in muzzle flash

CONCLUSIONS

- **Weapon fouling mass and chemical analysis testing demonstrated the effect of propellant formulation of buildup of on M4A1 bolt assemblies.**
- **Inorganic additives to propellant formulations (flash suppressant, de-coppering agent) and bullet jacket metal migrate from the gun barrel to the bolt through the gas port.**
  - De-coppering agent facilitates migration of copper
  - Potassium in flash suppressant forms potassium carbonate and supports basic copper carbonate formation
- **A reduction of inorganic additives to propellant formulations improves fouling characteristics**
- **A reduction of flash suppressant can be offset by reduced flame temperature to yield comparative muzzle flash output.**
- **Sample 6 is superior in terms of bolt/bolt carrier assembly fouling, and is capable of meeting cartridge specifications.**

ACKNOWLEDGEMENTS

- Saint Mark’s Powder (SMP)
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- Aberdeen Test Center (ATC)