TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Advanced Surface Treatments for Armament Weapon Systems

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Durable Solid Lubricant (DSL)

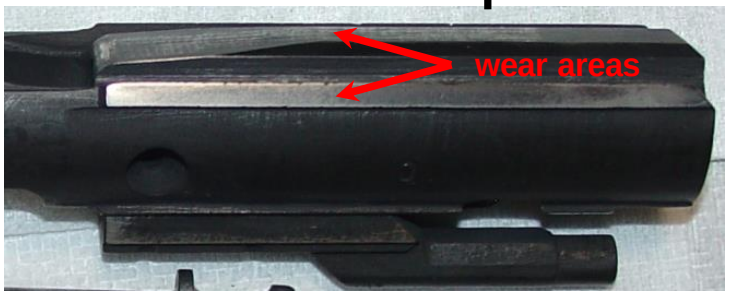
- Problem
  - Reduce or eliminate lubrication requirement for reduction in maintenance and increased reliability for small arms
  - Ability to provide correct combination of wear resistance, optimized friction coefficient, corrosion resistance, and anti-fouling/material transport behavior in the presence of propellant residue and environmental debris

- Approach
  - Implementation of advanced surface treatment to provide Durable Solid Lubrication (DSL)

- Objectives
  - Improve reliability and maintainability of small arms with specific emphasis on operation in extreme environments
  - Reduce or eliminate the need for conventional lubricants in weapon action components

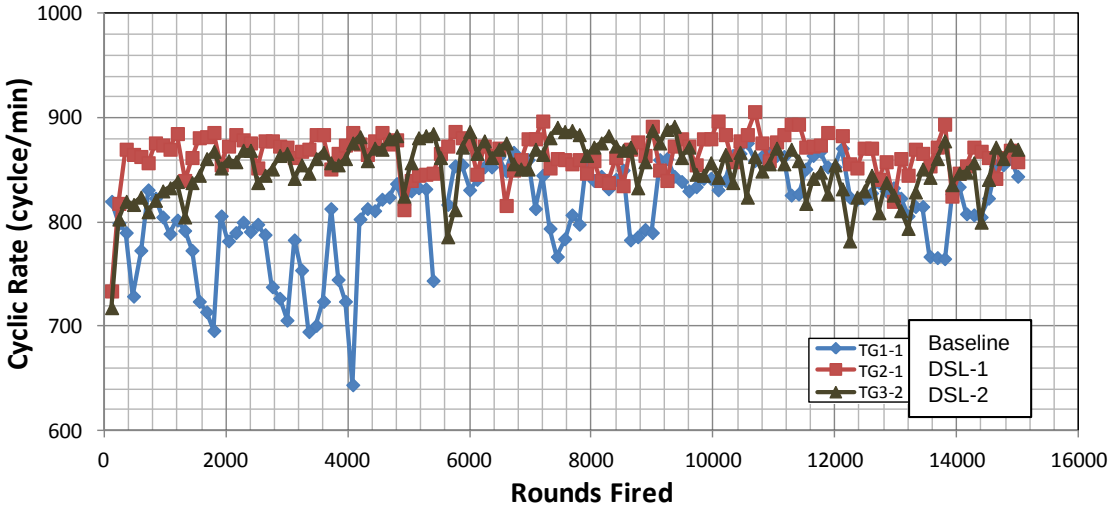
Demonstrated Results

After 15,000 rounds (ambient):

	Baseline Phosphate	Solid Lubricant Coating
Bolt carrier	 ~75% worn	 <5% worn
	 ~90% worn	 <5% worn
Bolt	 ~90% worn on body, ~50% on lugs	 <5% worn on body, ~10% on lugs
	FIRED WITH CLP	FIRED DRY

% worn = % totally exposed substrate

Demonstrated Results



The DSL weapon systems performed as well or better than the CLP lubricated baseline under ambient testing conditions

- **Increased weapon reliability**
- **Decreased wear on critical sliding surfaces**
- **More consistent cyclic rates**
- **Easy maintenance/cleaning with no CLP**

Detailed Description

- Technology Details

1) A durable solid lubricant deposited on the surface of substrate material, characterized by specific properties based on
    a) Hardness
    b) Thickness
    c) Coefficient of Friction
    d) Corrosion Resistance

2) A durable solid lubricant eliminating the need for conventional liquid lubricants

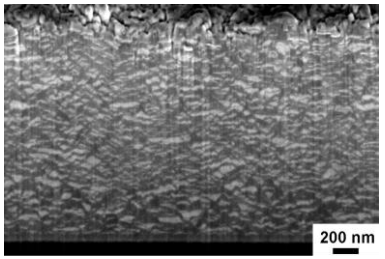
3) A durable solid lubricant providing:
    a) low friction; elimination of jamming related failures of sliding components resulting in increase component reliability
    b) increased component wear life; highly resistant to wear and eliminating hydrogen embrittlement factors from standard phosphate treatments resulting in longer lasting parts
    c) corrosion protection in all relevant environments
    d) improved maintainability; promotes ease of cleaning and reduction in active maintenance

Background

Self-Lubricating Nanocomposites

Nanocomposite and multilayer coatings with SOLID based lubrication:

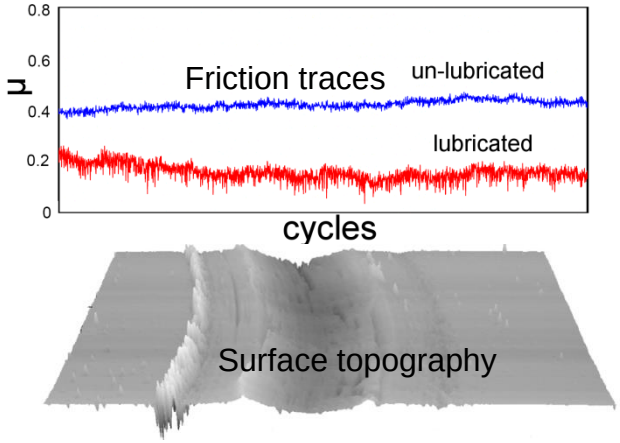
Applicable to:
- Weapon action components
- Vehicle action components
- Manufacturing/Machining operations
- Advanced oil-free turbomachinery

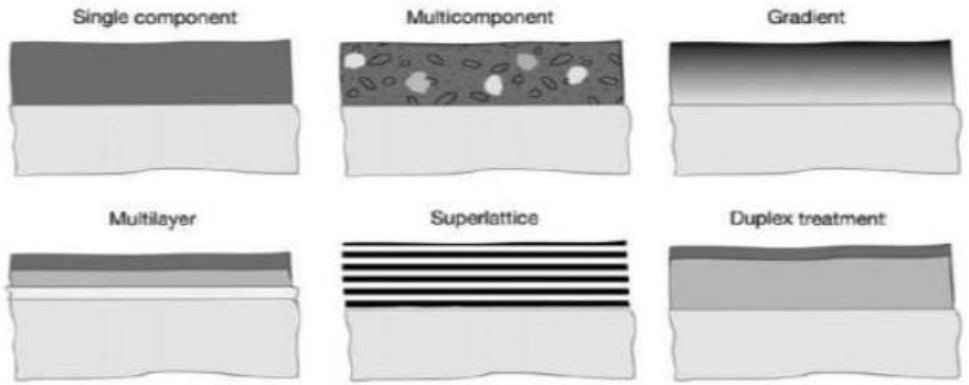


Cross-section of NC coating. Nanoscale solid lubricant (light phase) encapsulated in hard matrix (dark phase).

Allows:
- Elimination of conventional liquid lubricants
- Increased reliability of parts, decreased logistical burden

Bench scale tribological testing:





- Up to 80% reduction in friction
- Up to 15x reduction in wear

Technical Approach

Three Stage Approach: Innovative and Tailored Test Protocols Developed

1) Stage 1
   - Broad screening tests to include rapid Ball-on-three-disk (BOTD) tribological testing and coatings characterization
   - Down-select promising ca

27 different material combinations eval'd

2) Stage 2
   - Targeted bench-scale tribological testing
     - Testing to accurately simulate weapon action
   - Down-select promising

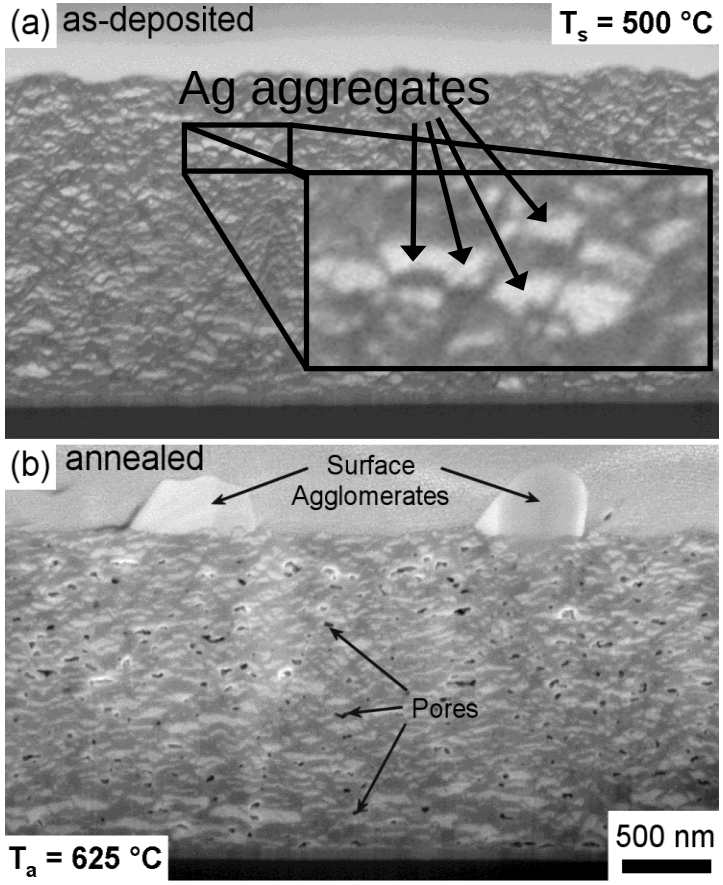
6 different material combinations eval'd

3) Stage 3
   - Live Fire Testing

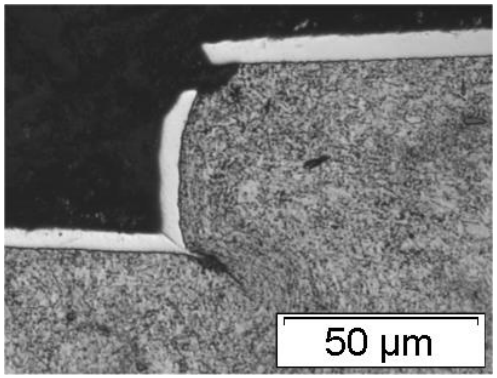
4 different material combinations eval'd

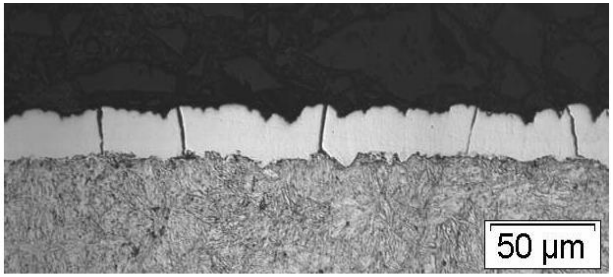
Stage 1 Characterization

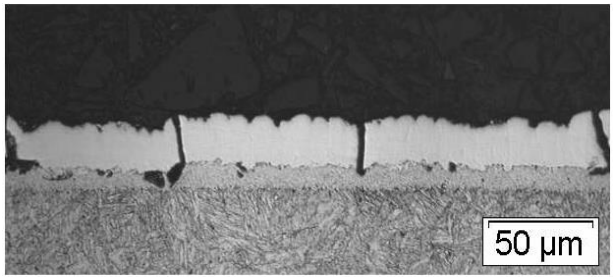
Nanocomposite structure



Porosity/cracking/defects



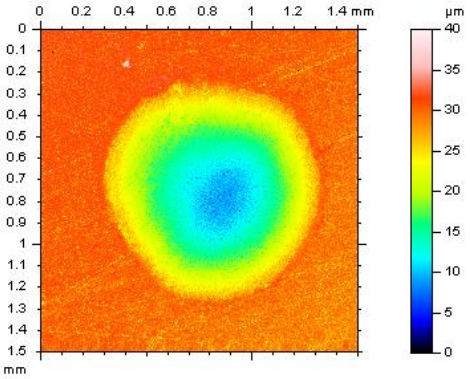


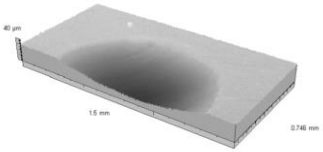


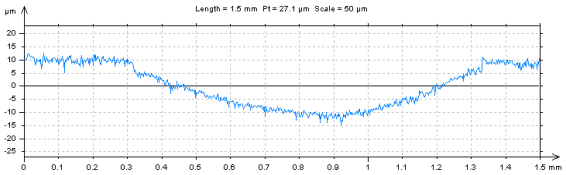
Stage 1 Characterization

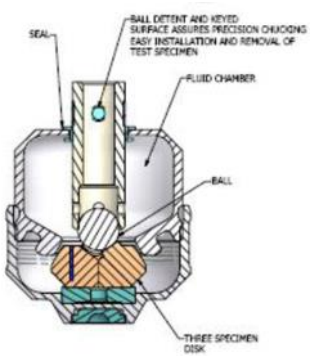
Stage 1:

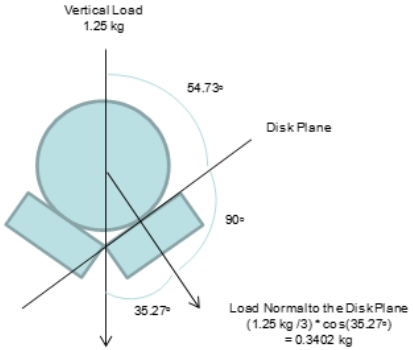
- Broad and rapid screening of fundamental properties using ball-on-three disk (BOTD tribological testing apparatus developed for this program)
  - **27 different material combinations evaluated**
- Broad spectrum of environments tested for each
  - Dry or with CLP (lubricant)
  - Temperature - 25 versus 250 °C
  - Sand or no sand

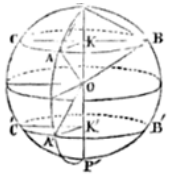












$$r_{scar} = (d/2) + (w^2 / 8 * d)$$

$$V_{scar} = \pi * d^2 * (r_{scar} - d / 3)$$

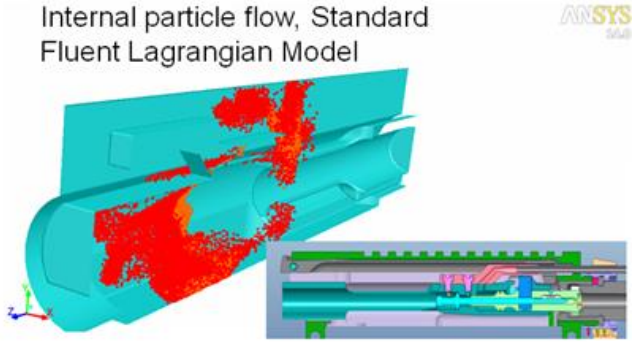
*Source: Institute of Tribology and Coatings, Sugar Grove, IL

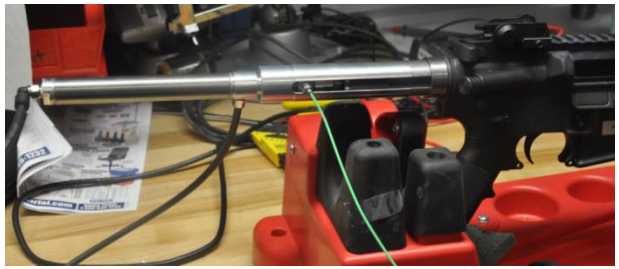
Parameters (Rotational Speed, Test Duration, Cycles, Load, Contact Pressure, Environment, Temperature)

Stage 2 Characterization

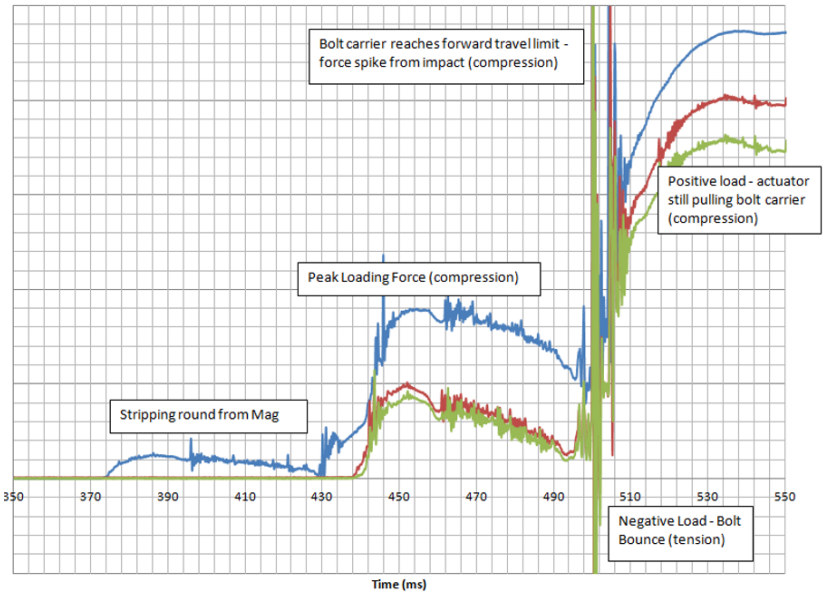
Stage 2:

- CFD Modeling and Simulation, Peak force analysis, and Targeted bench-scale evaluation using Slide-Rail-Simulator for quantitative evaluation of weapon interfaces.
  - **6 different material combinations evaluated**





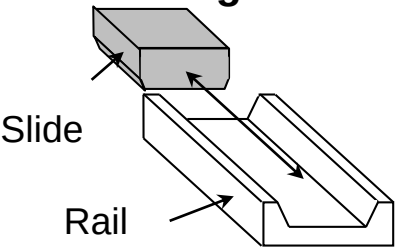
Developed/Fabricated bench scale test hardware to measure peak loading/extracting forces.

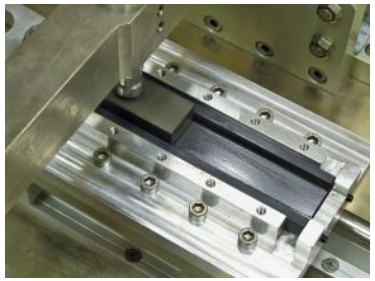


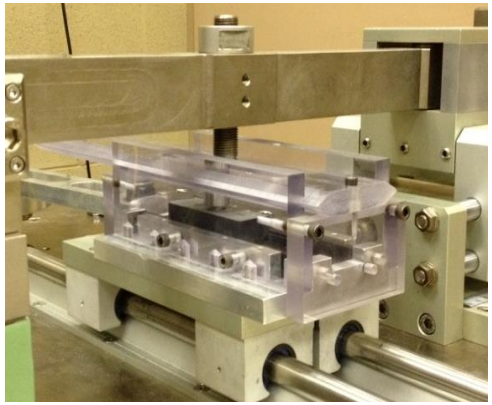
Peak loading force comparisons

Stage 2 Characterization

Stage 2:

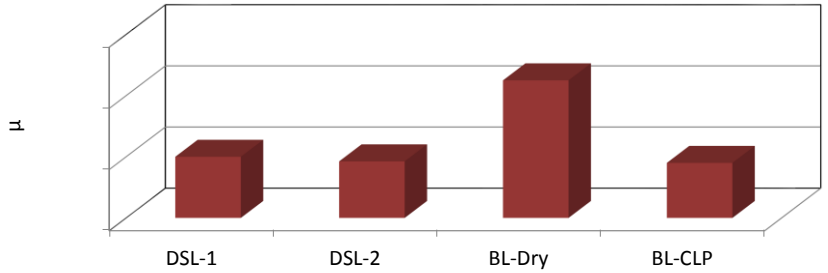




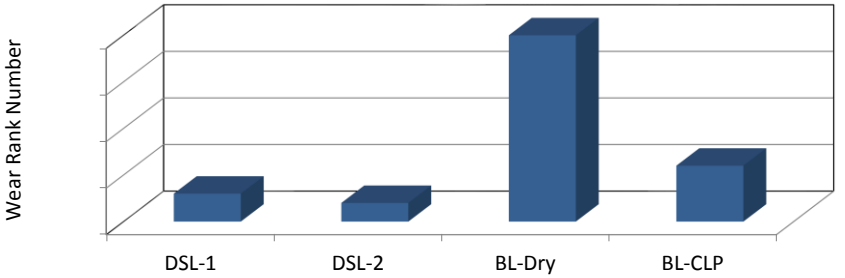


- Slide-Rail Simulator (SRS)
  - Wear and friction behavior in relevant configuration
  - Cyclic reciprocation simulates weapon motion
  - Contact geometry mimics weapon components
  - Contact stresses based on dynamic modeling
  - Fully instrumented for normal and tangential load

Coefficient of friction



Wear number (lower is better)



Stage 3 Live Fire Testing

- **Stage 3**: Live Fire Testing DSL fired dry versus baseline with CLP

Test Operating Procedures	Reference TOP 3-2-045	Demonstrated
Ambient	Section 4.3	DSL **Improved Performance**
Hot (160F)	Section 4.5.1	DSL **Improved Performance**
Cold (-60F)	Section 4.5.1	DSL **Equivalent Performance**
Sand/Dust	Section 4.5.4	DSL **Equivalent Performance**
Salt/Fog	Section 4.5.7	DSL **No chemical reaction / no corrosive buildup**
Unlubricated	Section 4.22	DSL **>4X increase in rounds fired w/out stoppages**

Path Forward

Future Testing:

- Limited Military Utility Assessments (LMUA)
  - Cold weather testing at Ft. Richardson, AK
  - Ft Benning, MCoE

- ATC Confirmatory Testing (FY15)
  - Technology Transition Agreement (TTA) signed with PMSW
  - Completion of ATC testing will achieve TRL 6

Summary

- **Warfighter Payoff**
  - Increased component wear life
    - More wear resistant and long lasting parts
  - Increased reliability
    - Reduce/eliminate jamming related failures in weapon action components
  - Improved maintainability
    - Promote ease of cleaning and reduction in Active Maintenance

- **Development of innovative lab scale test protocols**
  - Developed a standardized process to support future surface treatment characterizations

- **Additional applications for Armament System action components**
  - Future development work supported through Joint Service Small Arms Program (JSSAP) Office