



***Adaptive Graphite Coatings Improve Fit and Function
of Pistons, Turbos, Bolt Carrier Groups and Other
Precision Devices***

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Coating Background

- Graphite based Additive Abradable Powder Coatings (AAPC) were developed and introduced to the commercial automotive market in 2000
 - Low cost geometric refinement and efficiency improvement for powertrain components
 - Specific areas of improvement: fit and sealing
 - Over **16 million** automotive components coated to date
- Graphite AAPC is protected by patents in the USA & key global locations
- AAPC formulations allow for infinite variations of hardness, texture and particle size that have been proven in a variety of applications
- AAPC is applicable for all manufacturing levels ranging from prototyping to high volume production

Value Fundamentals of AAPC - “A Perfect Fit Every Time”

- Improves efficiency
- Lifelong geometric improvement to components (typical thickness 20μ to $200+\mu$)
 - Build devices tight – causing light interference fit
 - Final geometry laps in during initial operation
- Eases challenges - tolerancing, stack-up, thermal expansion
- Reduces clearances
- Cuts NOISE



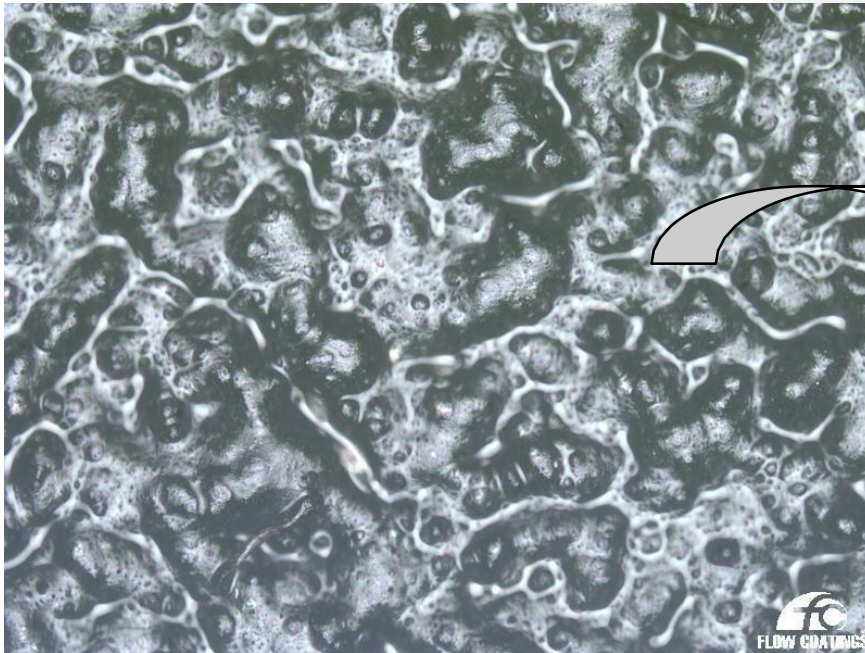
- Reduces friction - stabilizes oil film
- Eliminates scuffing
- Economical, scalable powder coating process
- Environmentally friendly

Self-polishing, Additive Abradable Powder Coatings are 'rough / fuzzy' as applied. They wear into the shape of the mating surface upon initial operation. Lasting geometric refinements of components improve fit, efficiency and durability. Applications: lubricated/dry, hot/cold, sacrificial/permanent.

Prior to Break-In

Magnifications
~150X

After Break-In



Initially, surface texture provides quick wear-in, followed by asymptotic decline in wear rate

Long term - ideal tribological surface has:

- Polished Plateaus (Low RpK)
- Random Crevices (High RvK)

Stribeck Fitting™ - in an operating engine AAPC will find and preserve the lowest friction piston geometry for each bore

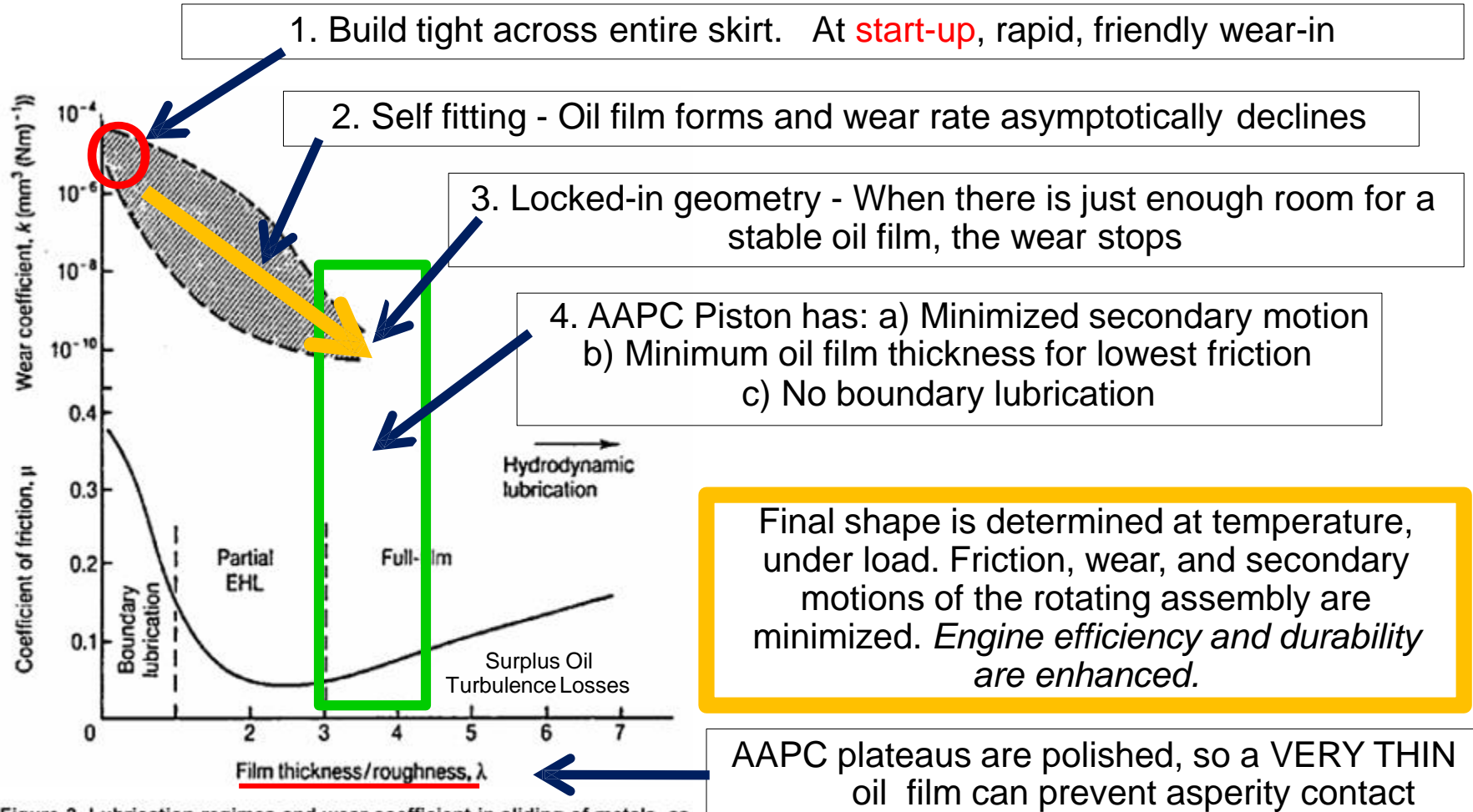


Figure 2. Lubrication regimes and wear coefficient in sliding of metals, as a function of λ (reproduced from Hutchings, 1992).

source: www.scielo.br/img/revistas/jbsmse/v29n1/a09fig02.gif

How It Works On Pistons



Improved Fit

- Build it too tight
- AAPC hones piston to the ideal fit *for EACH bore*
- Reduces secondary motion in rotating group
- Improves ring flutter, seal and life
- Reduces slap and noise
- Permanent geometric refinement

Improved Friction

- Creates optimum, stable oil film across entire skirt
- Break-in event seeks minimum friction per Stribeck diagram
- Enlarges contact area to spread load and lengthen oil leak path
- Tolerates foreign debris
- Provides long term scuff resistance

Secondary Motion of Pistons is Critical for Piston Ring Longevity

- Rock causes rings to work harder, flutter more, seal less
- Rock requires larger crevice volume
- Rock can pump oil around the rings
- APC stabilizes piston, keeps rings square to bore
- APC enables reduced ring tension for lower piston assembly friction
- APC reduces oil volume rings must handle



14.7L Cummins Diesel Engine – over 400k miles and continues to have low oil consumption

- NTC-300 855 CI (14.7 L) Cummins Gen III 400HP diesel
- Over **400k miles** on in-frame rebuild using coated pistons and fresh liners
- After rebuild **oil consumption reduced by 50%**

COATING THE PISTON SKIRTS
ALSO. THIS ENGINE STILL DOES
NOT NEED OIL ADDED BETWEEN
OIL CHANGES. I HAVE NOT
REMOVED A PISTON TO CHECK
WEAR AS IT IS NOT CALLED FOR
AT THIS TIME.

Severe Duty Piston Photos



- LSX Corvette 800 hp 'drift' race engine
- After 1 year ~ 400 hrs @ 7000+ rpm
- Unexpected excellent skirt condition
- Unexpected excellent ring condition
- Rod bearings also surprisingly great
- Former Don Garlits and Roush NASCAR engine builder



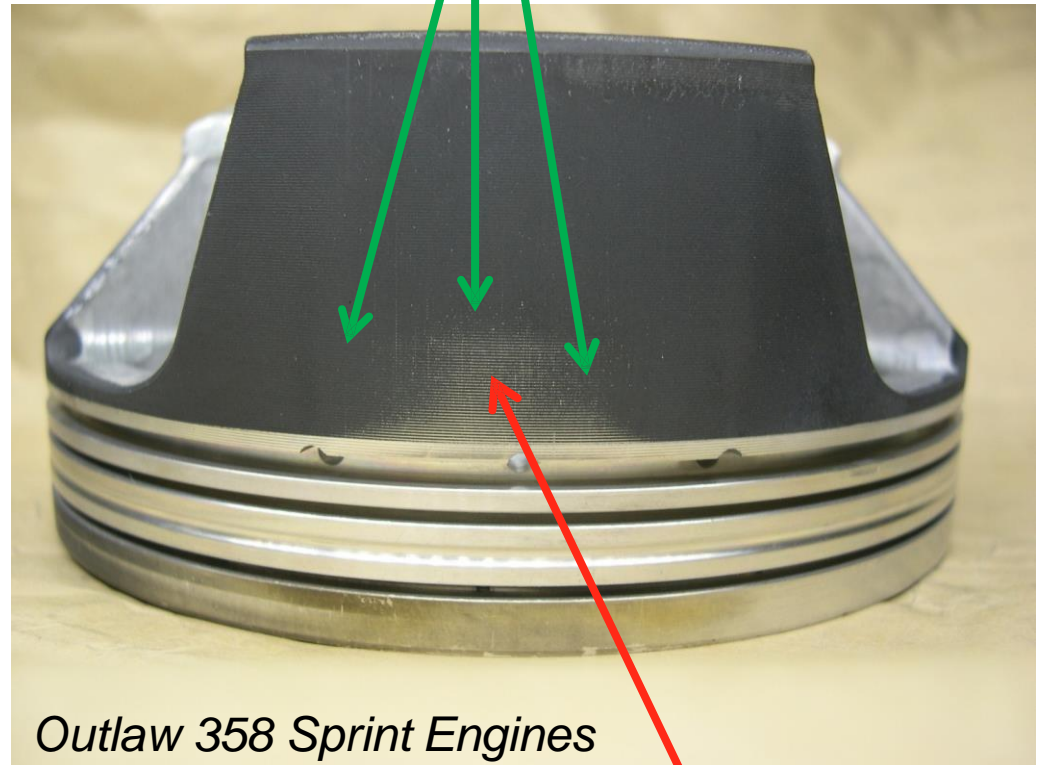
- 1600 hp alcohol truck pull - 12 time National Champion
- After Dyno + 25 pulls (piston cracked)
- Unexpected excellent condition
- Best ever pan vacuum
- Unexpected excellent skirt condition
- Unexpected excellent ring condition

Reduces Peak Loads and Prevents Scuffing

- Enables stiff architecture to achieve the perfect fit
- ...with no risk of scuffing

Scuffing Epidemic Cured

AAPC redistributes load to adjacent areas

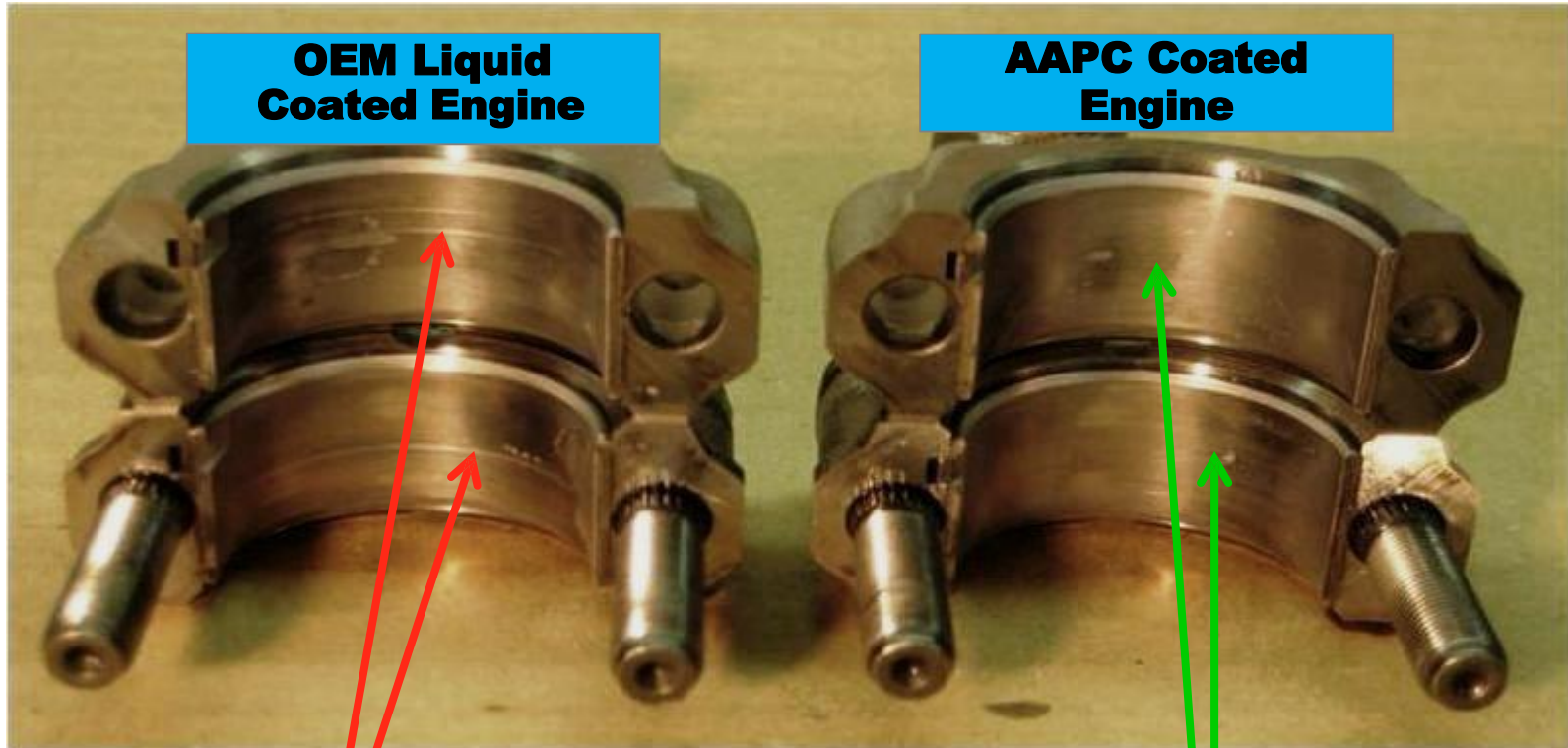


Outlaw 358 Sprint Engines

After duty cycle, highly loaded, scuff prone area is visible

Rotating Group Benefit - Bearing Life

Visual Engine Parts Comparison After 2500 Miles Racing

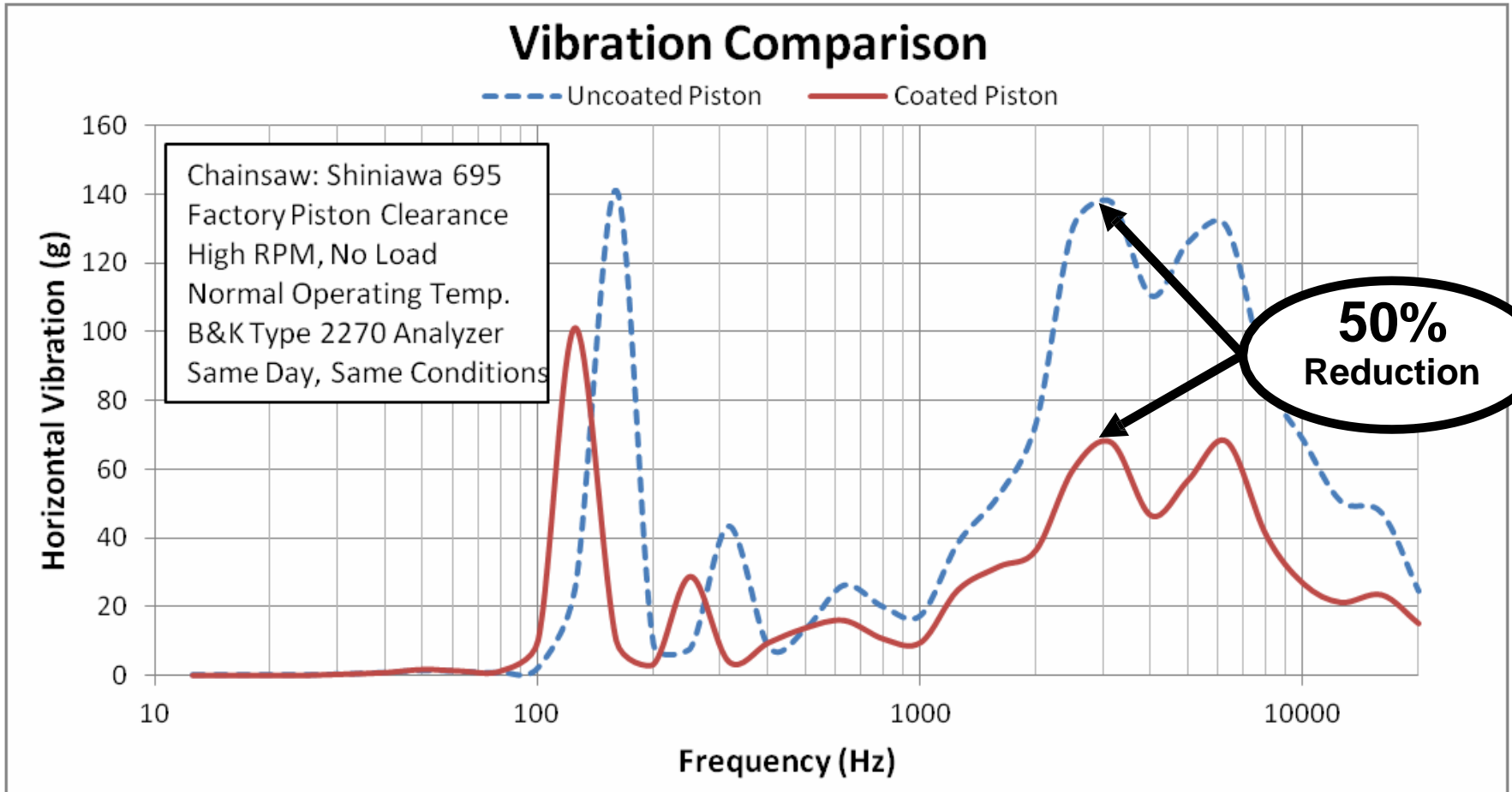


Typical Failure Mode

Delayed Onset

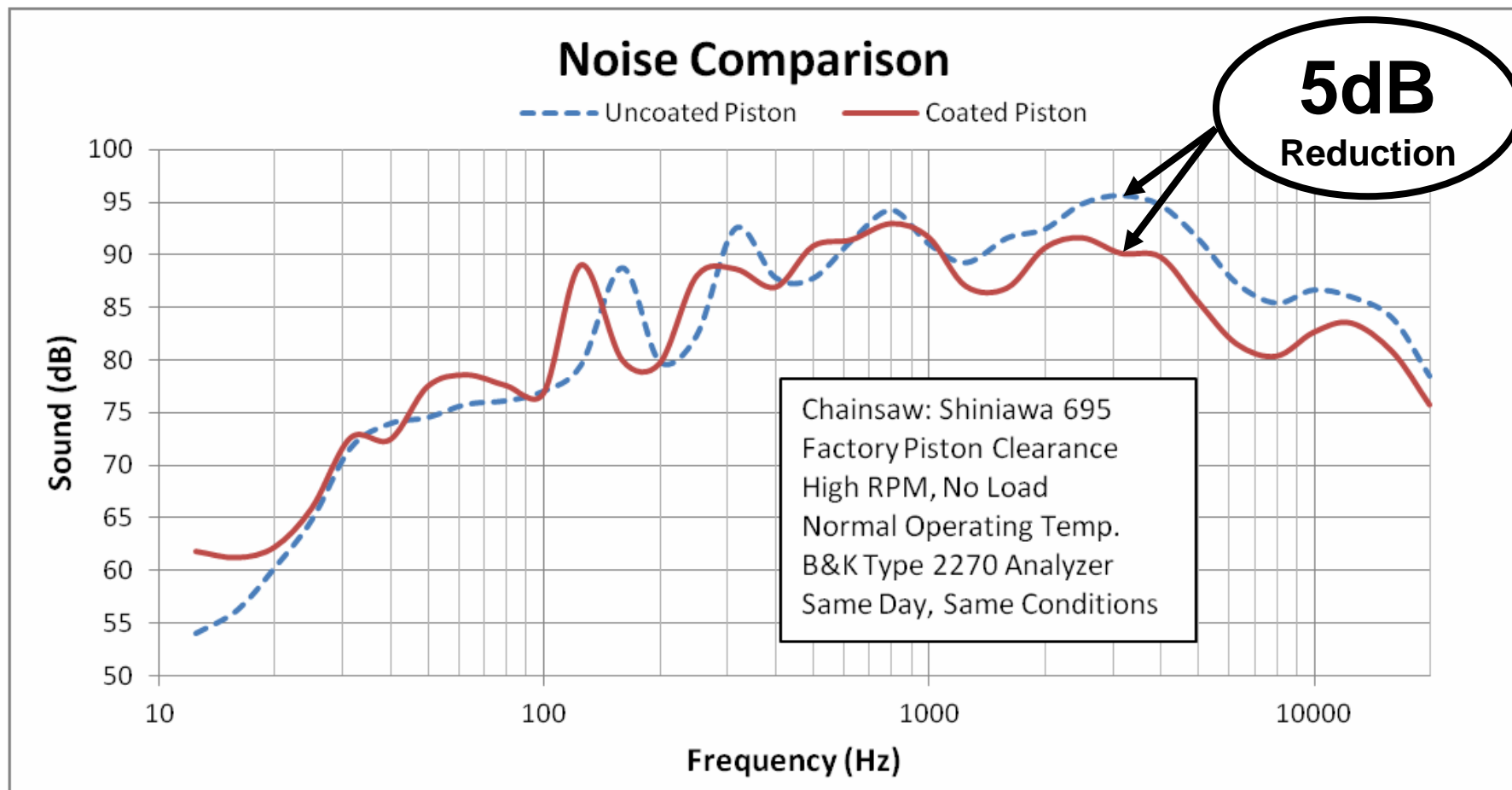
Reduced Shock Loads Preserve Bearings

AAPC Piston In A Chain Saw Engine - Vibration



Coating reduces prismatic spectrum vibration

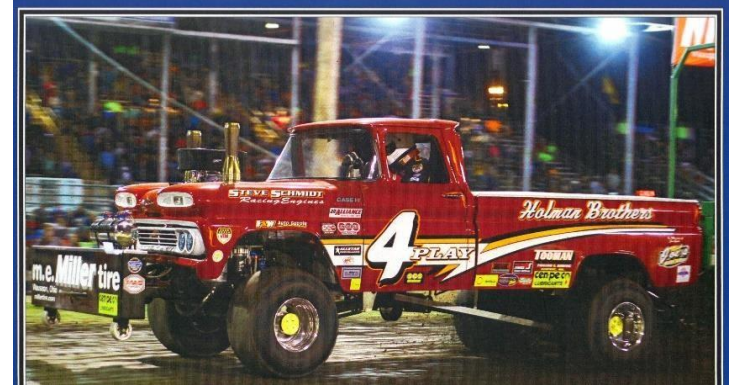
AAPC Piston In A Chain Saw Engine - Noise



Coating reduces noise over audible range

AAPC has been a 'Huge' success on Pistons

- Race market > 15,000 Engine Jobs to date.
 - Sustained 30-40% annual growth for 5 years via word of mouth
 - Drag race, circle track, endurance, tractor pull
 - Gas, alcohol, diesel, JP8, nitromethane
- Significant Remanufacturing Applications
- Licensed UEM, L2LSE, L2LW
- Advanced Engine Development
 - Next Gen Combat, Small Engines, Stationary Power
 - Specified in drones, passenger aircraft
- Restoration of used pistons – not a band-aid
 - Better performance and durability



Graphite Powder Coating Documented Benefits

<p>Pistons ➤ All Types</p>		<ul style="list-style-type: none"> ▪ More power across RPM range ▪ Better durability of piston/rod assembly and bores ▪ Lower noise ▪ Cleaner combustion (oil control) ▪ Higher compression after service life ▪ Reduced secondary motion
<p>Blowers</p>		<ul style="list-style-type: none"> ▪ Improves sealing ▪ Improves volumetric efficiency ▪ Dry or fueled applications
<p>Timing Gears</p>		<ul style="list-style-type: none"> ▪ Sets backlash at assembly ▪ Reduces noise ▪ Boosts efficiency in gear pumps
<p>Bearings</p>		<ul style="list-style-type: none"> ▪ Reduce clearances ▪ Lower noise ▪ Scuff/Scoring protection

Graphite Powder Coating Documented Benefits

<p>Pumps-</p> <ul style="list-style-type: none"> ➤ Gear ➤ Gerotor ➤ Vane ➤ Variable 		<ul style="list-style-type: none"> ▪ Higher efficiency ▪ Reduced secondary motion ▪ Extended performance ▪ Improved manufacturability
<p>Compressors</p> <ul style="list-style-type: none"> ➤ Screw ➤ Scroll ➤ Piston <p>Expanders</p>		<ul style="list-style-type: none"> ▪ Higher efficiency ▪ Reduced secondary motion ▪ Extended performance ▪ Manufacturability
<p>Spool Valves</p>		<ul style="list-style-type: none"> ▪ Lower leakage ▪ Improved control ▪ Manufacturability
<p>Snowmobile Carb Slides</p>		<ul style="list-style-type: none"> ▪ Provides enhanced seal ▪ Improved durability ▪ Enables proper idling

Self-Polishing Graphite Coatings Improve Pump and Seal Performance

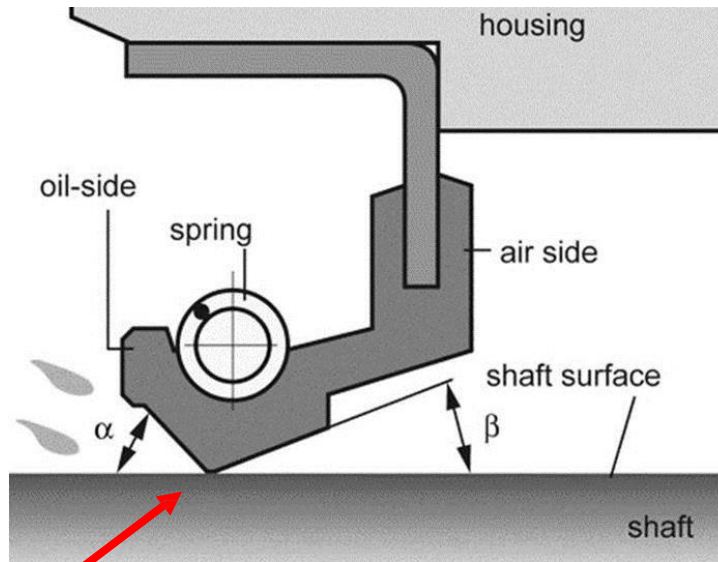
- Graphite coatings reduce friction, making everything run smoother, quieter and easier
- Graphite coatings polish themselves to a perfect fit, eliminating gaps that can cause leaks
- Racing engine oil pumps coated with AAPC self-polishing coatings have 2x higher pressure at idle than uncoated
- Graphite coatings are inert and do not react with oils and transmission fluids
- Improves Engine Efficiency 7%
- Extends Part Life 300%
- Decreases Noise 50%
- Reduces Remanufacturing Costs – Cheap and easy to apply

Pumps

- Seals new/used gear and gerotor pumps to 'better than new' efficiency
 - Gear pumps and other gear-based mechanisms can be built very tight compared to conventional tolerances
 - The coating is then self-honed to the ideal shape for each contact surface during operation
 - Wear on the coating stops when the oil film is optimized per the relevant Stribeck Curves
 - A stabilized oil film prevents boundary lubrication and minimizes operational friction
- Higher pressures at low RPM – **100% Improvement**
- Permits downsizing (Size/Weight)
- Sand and debris tolerant
- Provides longer life
- Improves overall manufacturability



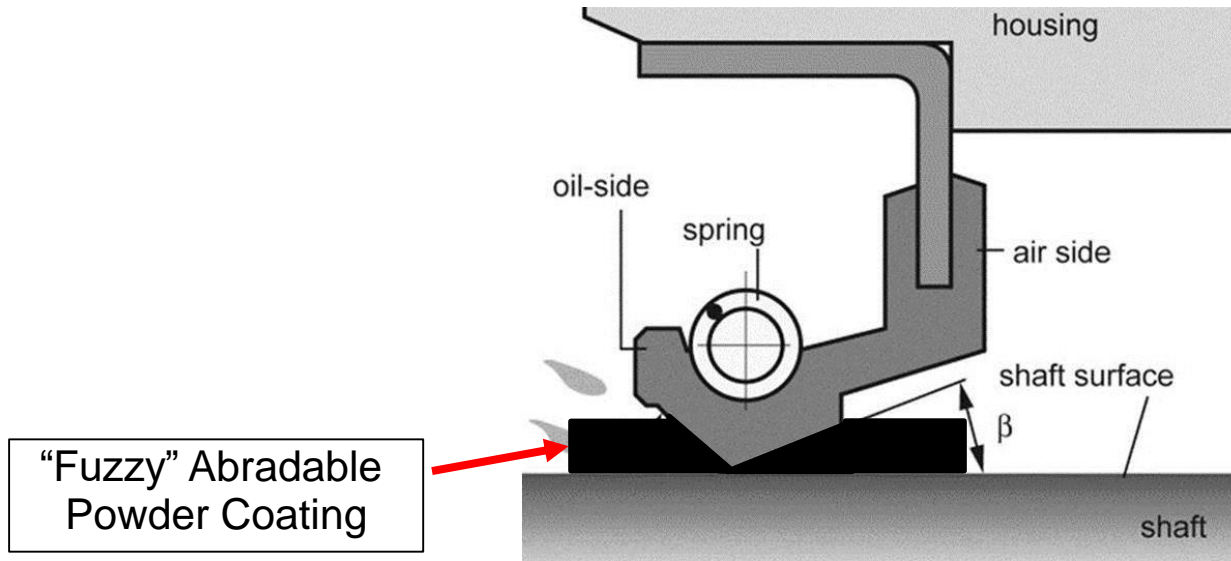
Shaft Seal Seat – Before Coating Shaft With Line2Line



Uncoated Shafts Can Wear Unevenly

- Small contact area with high pressure can lead to lip distortion
- Dust, dirt and other contaminants can enter seal area
- Surface scratches and gouges create leak paths
- Contact area is a small surface area, making leaks more likely

Line2Line Shaft Seal Seat



Self-polishing lip seal seat area

- Seat polishes conformal to seal shape during operation
 - Provides improved interference fit
- Friendly to seal material during and after break-in
- Keeps sand/grit away from seal
- Extends leak path of fluids thereby reducing unwanted oil flow
- Spreads contact area and supports seal when pressure gradients occur
- Improves concentricity of shaft/seal pair

Blowers/Compressors

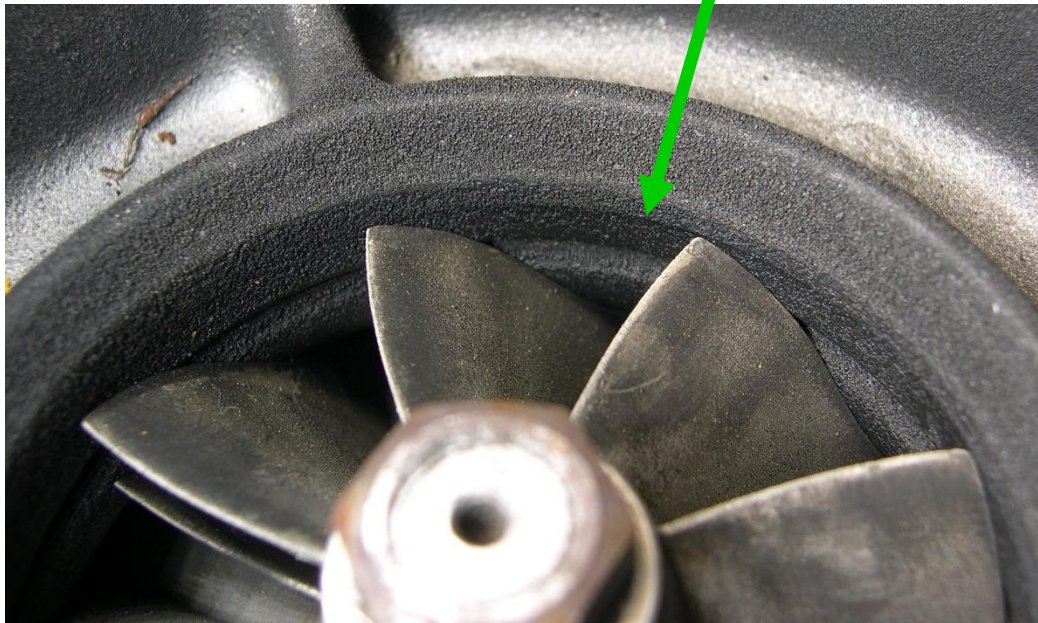
- Improves volumetric efficiency
- Reduces friction and heating
- Extends peak performance
- Enables refurbish and retrofit



Holset HD Diesel Turbocharger

- Rotor cuts perfect seal shape during operation
- Improves fuel economy
- Economical retrofit

Photos after 150K miles



OBSERVATIONS

A. THE TREATMENT TO THE PREVIOUS TURBO DEFINATELY INCREASED ITS RESPONSE TO CHANGES IN NEEDED POWER.

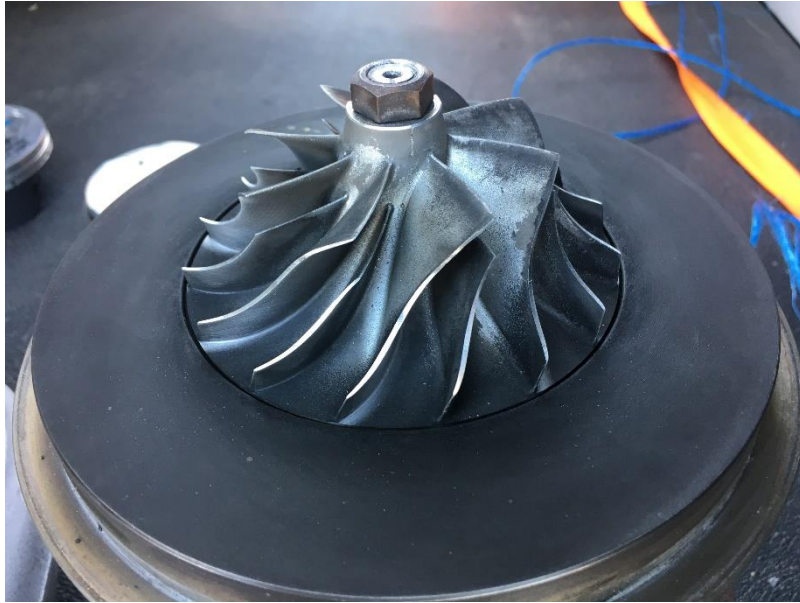
B. A FUEL MILEAGE INCREASE WAS DEFINATELY AQUIRED AS HIGH 6s AND LOW 7s WERE THE NORM. ABOUT 1/2 MILE PER GAL.

C. NO MECHANICAL PROBLEMS WERE ENCOUNTERED DURING THE USE OF THIS TURBO.

THIS TURBO WAS USED WHEN I PURCHASED IT, SENT IT TO YOU, INSTALLED IT AND NOW HAS ALMOST 200000 M, ON IT AND IS JUST WORN OUT.

I HOPE THIS NEW UNIT GIVES AS GOOD SERVICE.

Throttle Response - Abradable Seal Photos



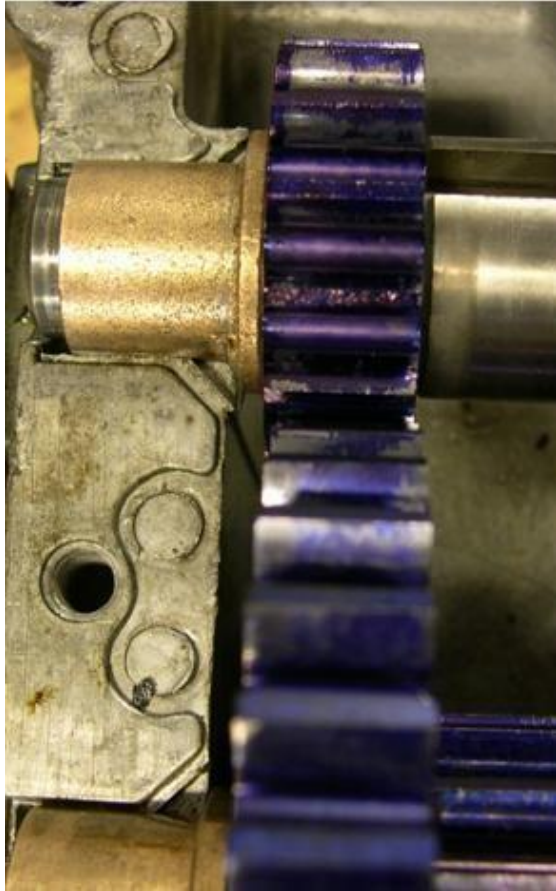
- 150,000 miles on coating
- Driver perceived better throttle response
- Driver reported significant mpg savings on known route & load over 1.5 years
- All tips evenly polished
- Rotor 'bedded' into thick coating
- Convenient retrofit improvement

Gears & Sprockets

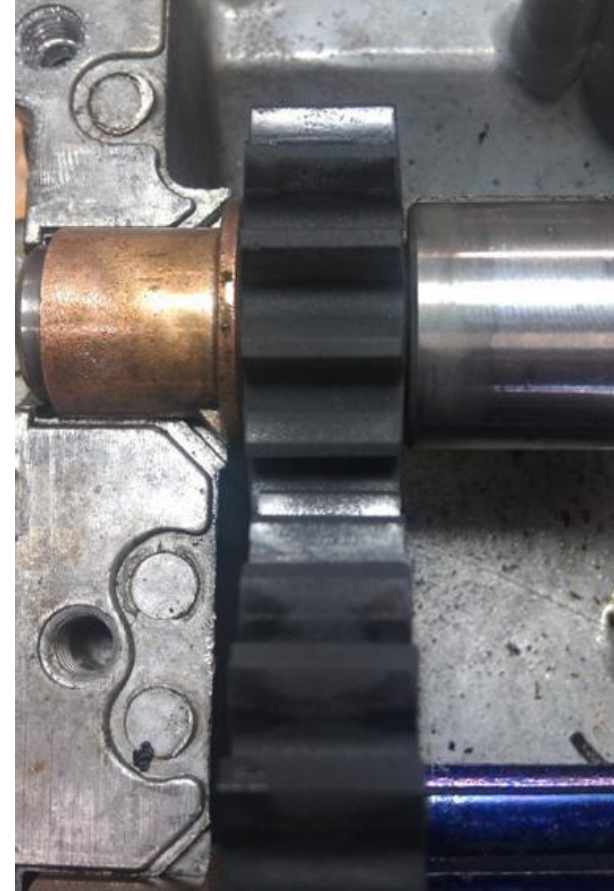
- Sacrificial shim coating
 - Simplifies assembly of geartrains
 - Controlled coating thickness spaces gears properly
 - Soft coating abrades away at contact area under operation
- Reduces backlash
- Reduces peak loads on chain



Gear Loading Surface Comparison



Bluing on the gears indicate areas which do not carry load when they run dry



An abrasible coating provides visibly more uniform loading across the gear tooth

Comparison - Coating on Gears for Setting Backlash

	Traditional Liquid	Line2Line Powder
Characteristic		
Appearance	Glossy, Silver	Satin-Black
Texture	Smooth	Textured
Thickness Range	Est. 5-75 μ	20-200+ μ
Thickness Control	Very Good	Very Good
Pencil Scrape Adhesion (Internal QFCW-23)	3H Very Good	3H Very Good
Pencil Hardness (ASTM D3363)	2H	2H
Solvent Rub Resistance (ASTM D5402)	Pass	Pass
VOC Content	High	Low
Oil Retention	Lower	Higher
Relative Processing Cost	High	LOWER
North American Availability	TBD	Available NOW

Coating Bolt Carrier Group - Abradable Graphite Coatings Enhance Reliability, Performance, Life of Weapon Systems

- Better Reliability In SAND
 - Little to no oil required
 - Seals out particles
 - Tolerates particles that enter
- Lower Friction, Cooler Operation, Longer Life
- Easier Manufacturing of Precision, Sand Resistant, Oil Free Mechanisms
 - Soaks up tolerances
 - Improves fit, function and oil films
 - Reduces noise, leakage and wear
- Reconditions Worn Components

Blowing Sand Test - Phosphate Best - Jams in 11 Rounds

<https://www.dropbox.com/s/6f4qibzu4dbecwg/200725%20Uncoated.MOV?dl=0>

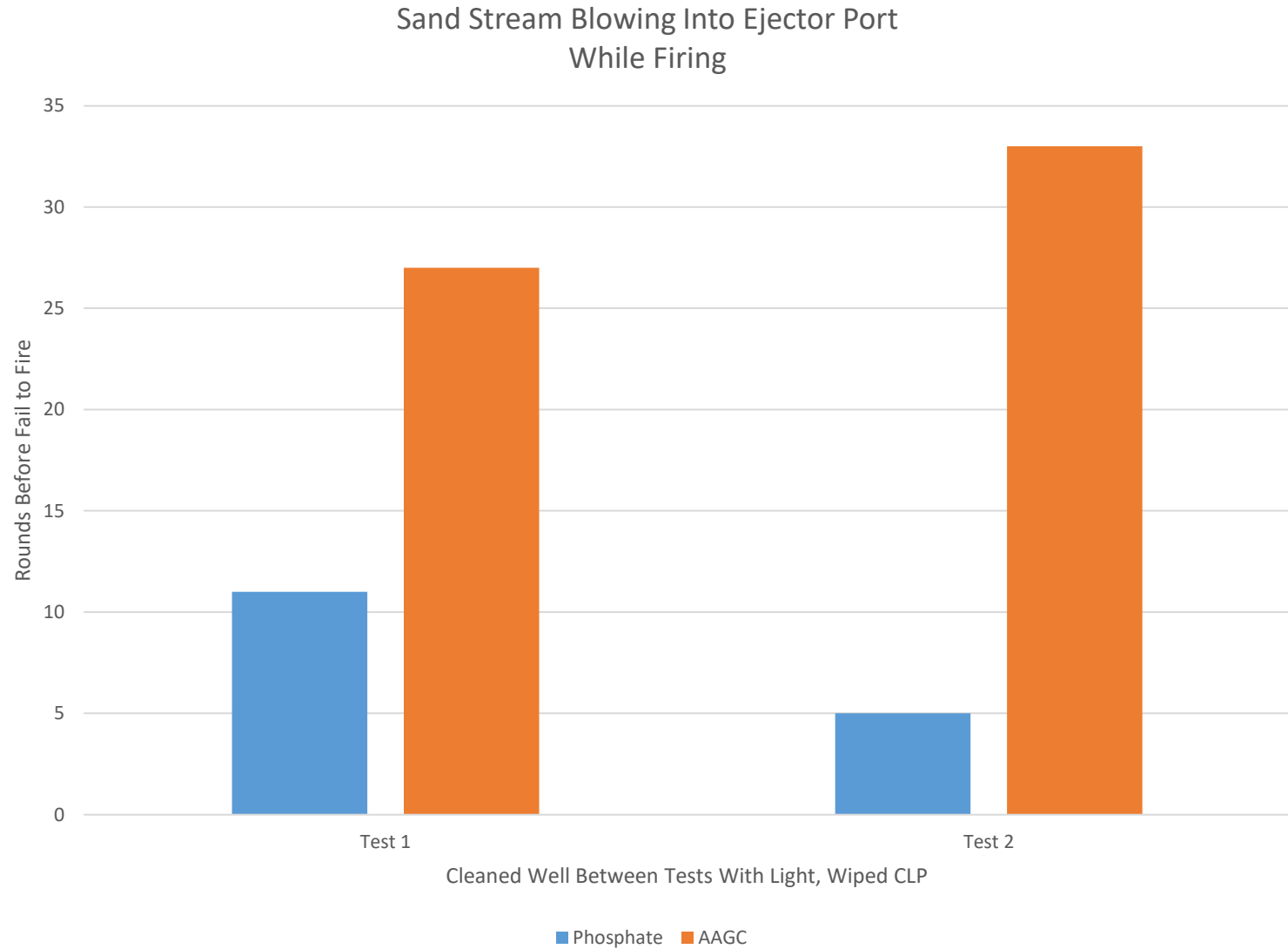


Blowing Sand Test - With AAGC Best - Jams in 33 Rounds

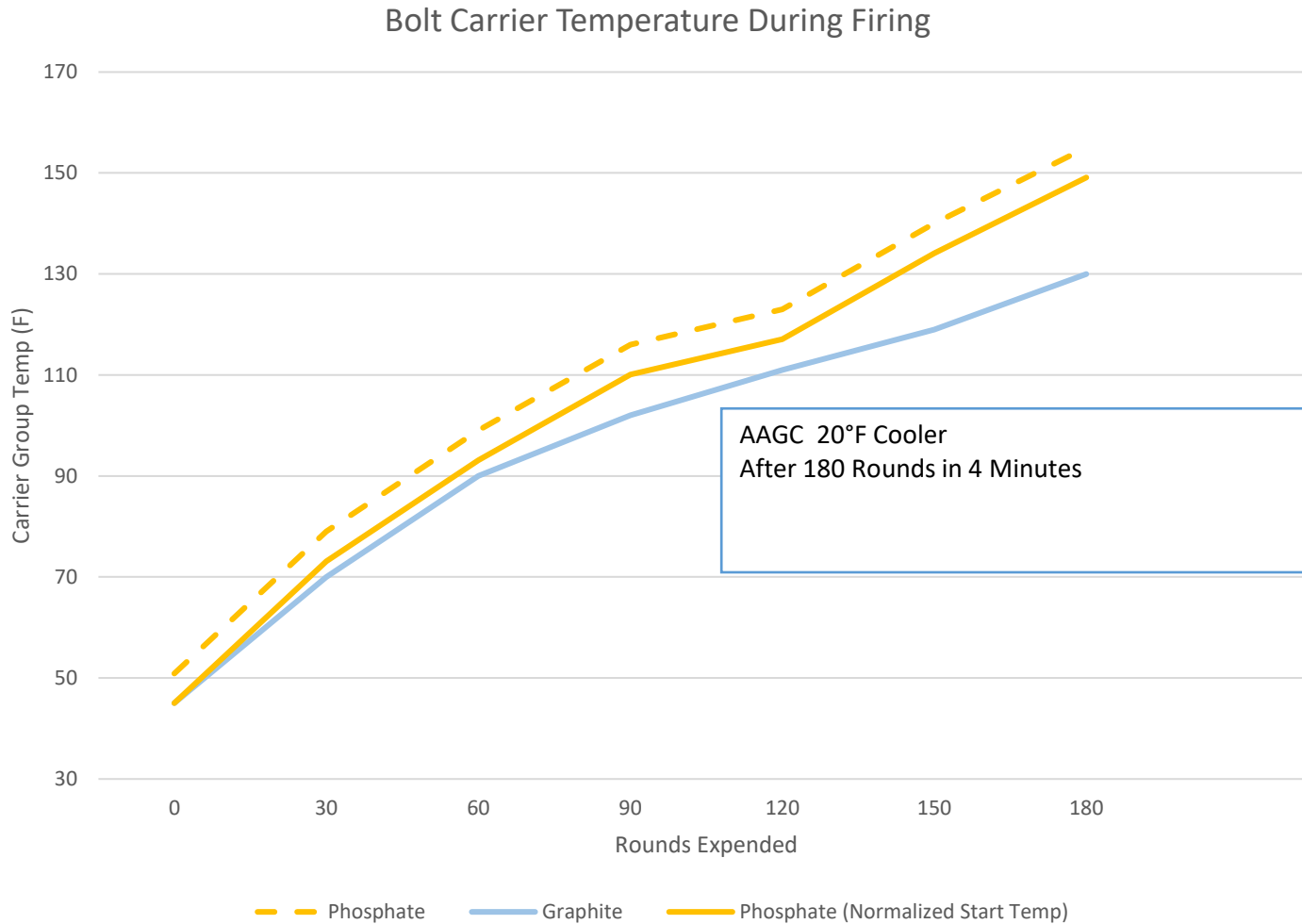
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AAGC Resists and Tolerates Sand & Needs No Surplus Oil



AAGC Reduces Friction To Keep Parts Cooler



AAGC's - Preliminary Gun Mechanism Summary

- Better Fitting Parts - Precise, Smooth Operation
- Keeps Sand Out of Jam-Prone Areas
- Reduces/Eliminates Need For Oil
- Reduces Thermal Signature
- Restores Components
- Reduces Friction
- Reduces Wear
- Extends Duty Cycle
- Extends Reliability
- Prevents Corrosion

