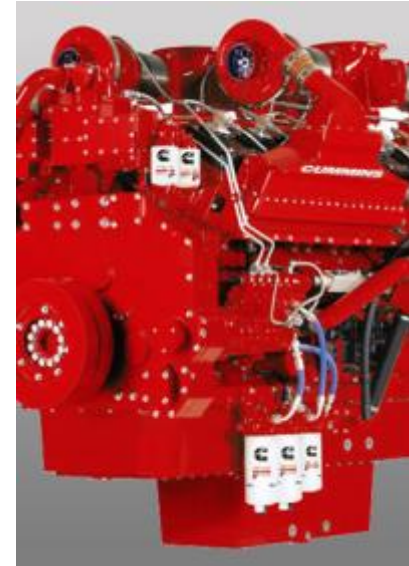




Piston Carbon Packing

Dan Richardson

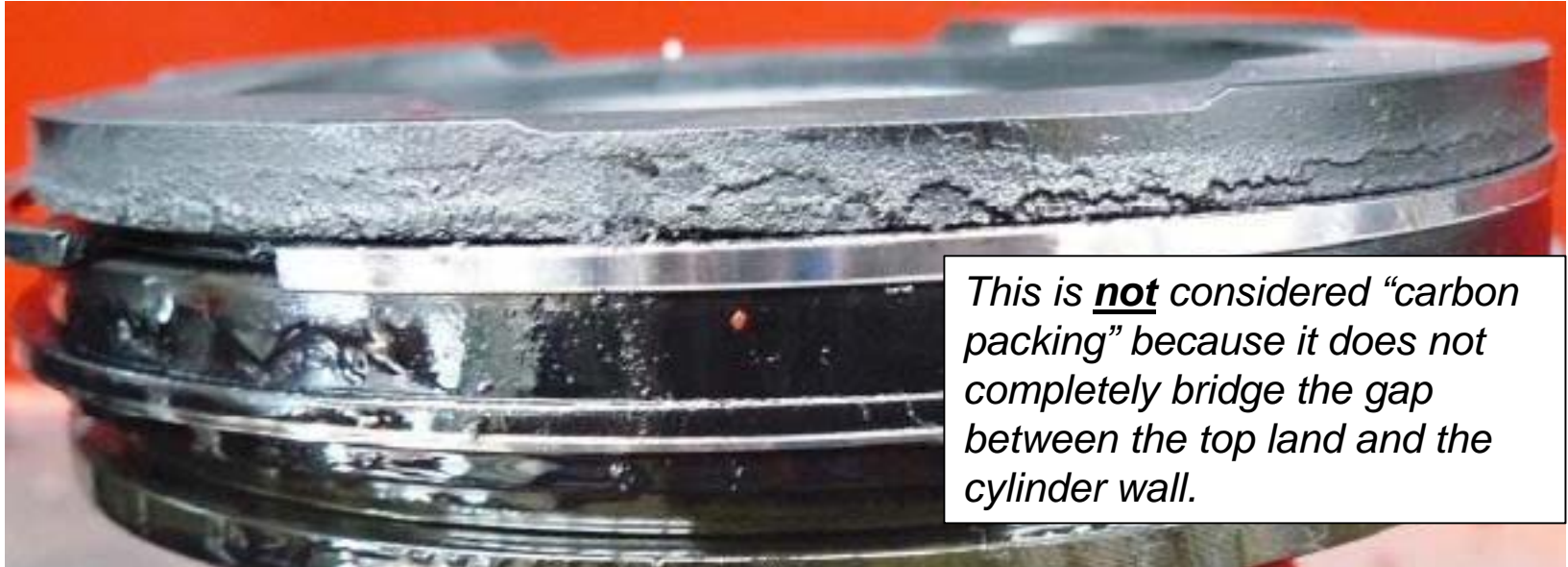
Lara Sherefkin



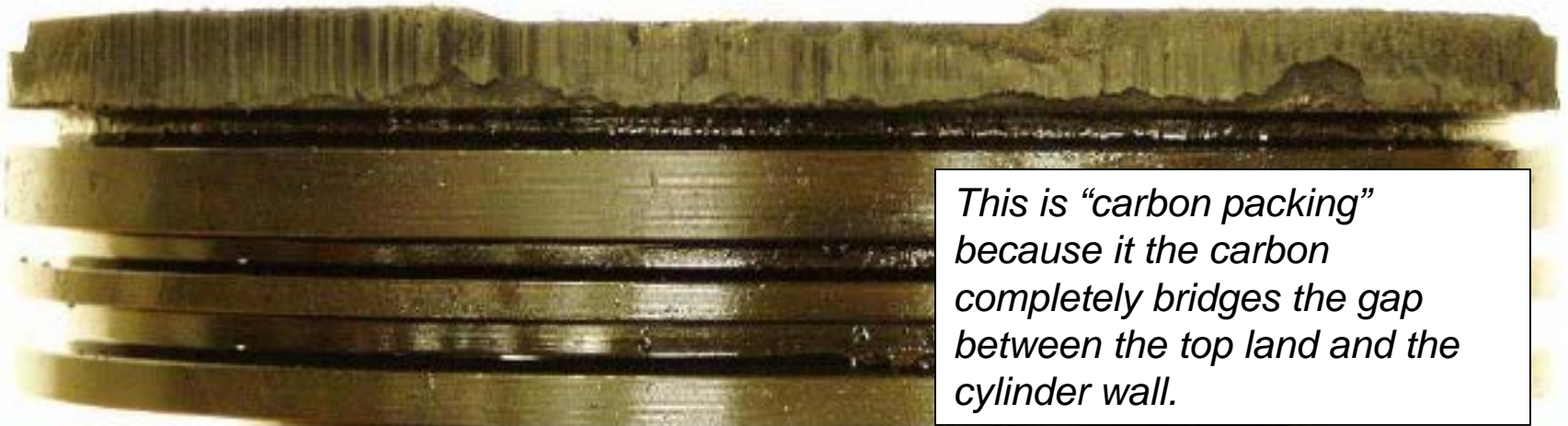
Piston Carbon Packing

EXAMPLES

Carbon Packing



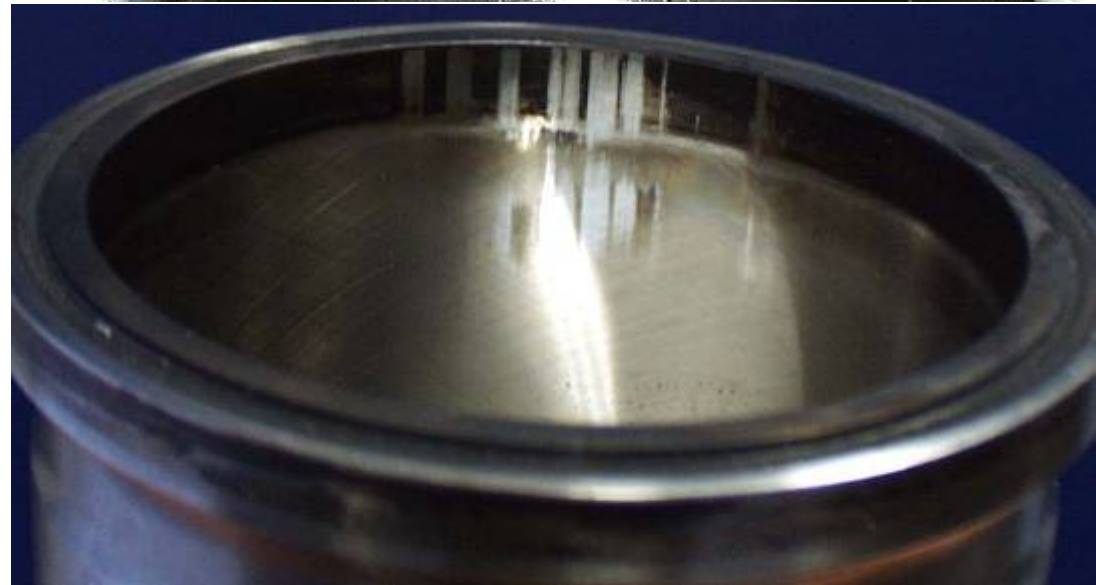
This is **not** considered "carbon packing" because it does not completely bridge the gap between the top land and the cylinder wall.



This is "carbon packing" because it the carbon completely bridges the gap between the top land and the cylinder wall.

Effect of Carbon Packing

- ***Excessive Carbon Causes***
 - ***Lack of Oil Control***
 - ***Incorrect Piston Temps***



On ISX engines currently dealing with high levels of carbon packing (2013), are occasionally seeing very low blow by in the field. Carbon blocking combustion gasses potentially.

- Dale Nauman (DFSE)

Dana/Perfect Circle



Piston Carbon Packing

MECHANISM

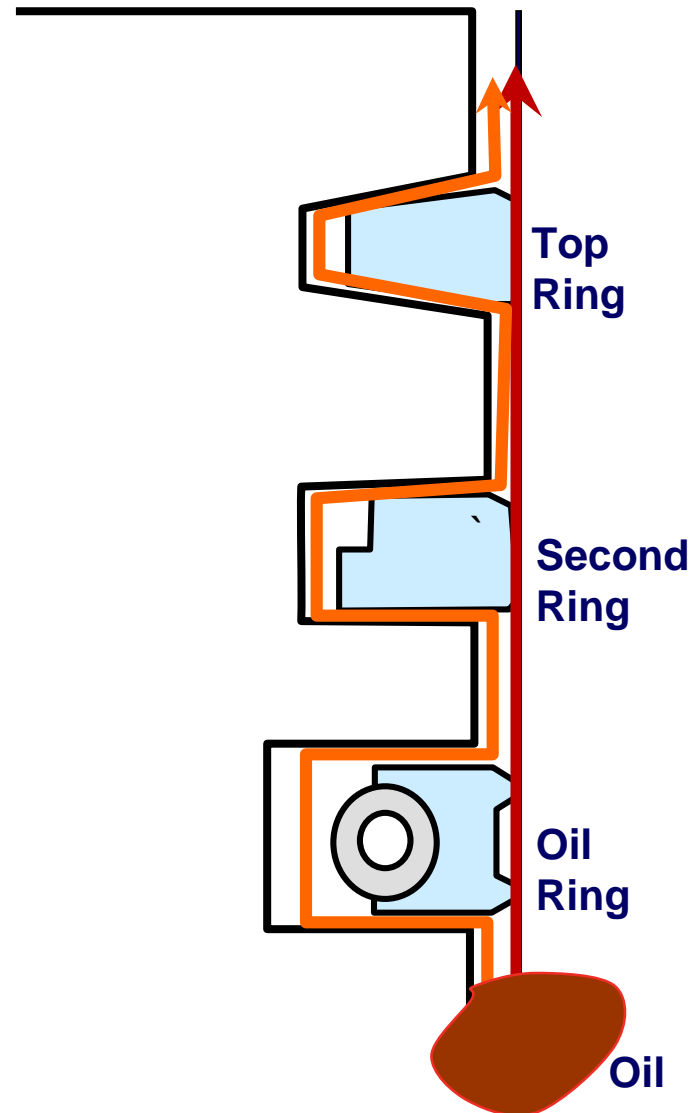


Oil Transport – Power Cylinder

- The ring need to seal oil from going up into the combustion chamber.

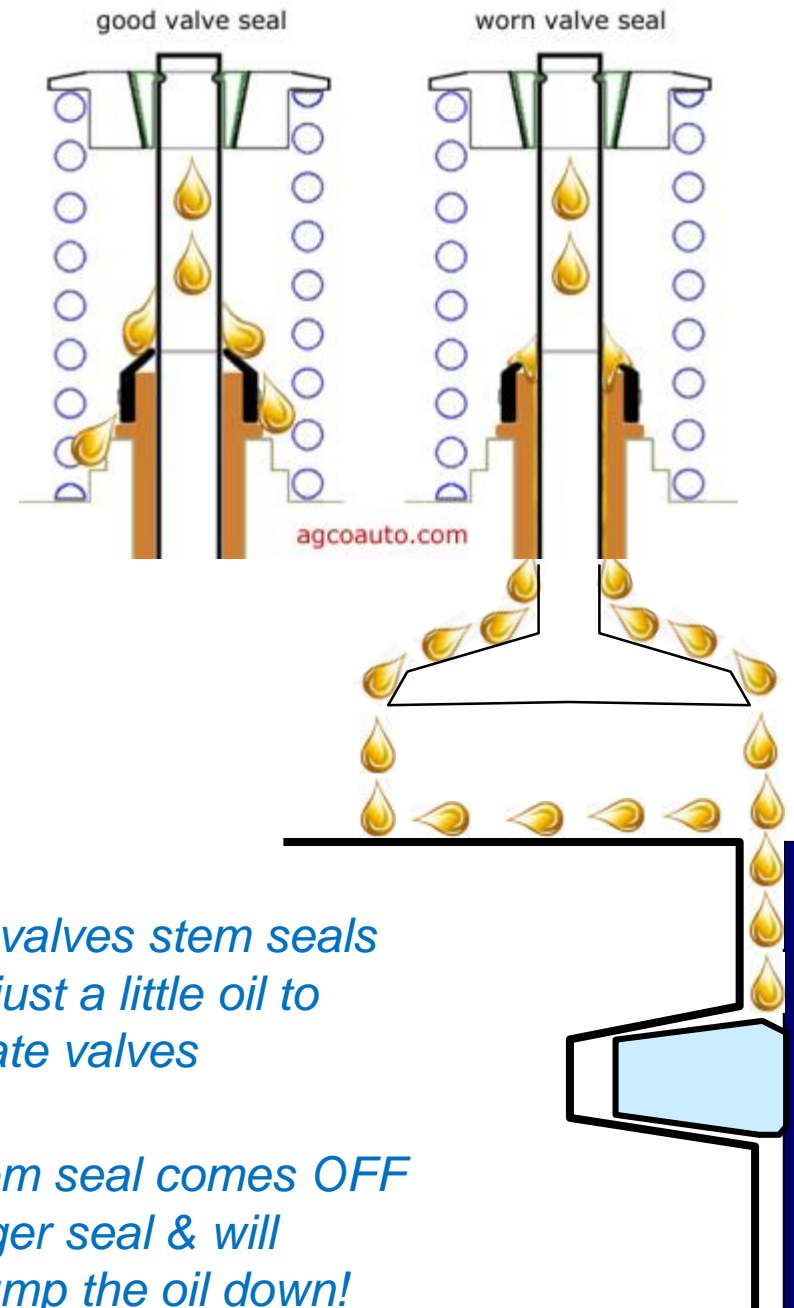
However:

- Oil will move up past the face of the rings.
- Oil move up around the rings.



Oil Transport - Valves

- The valves need to seal oil from coming down into the cylinder.
- Intake Valve Stem Seals may not seal oil.
- Intake Valve Stem Seals may come OFF valve.
- Oil will go down the valves into the cylinder

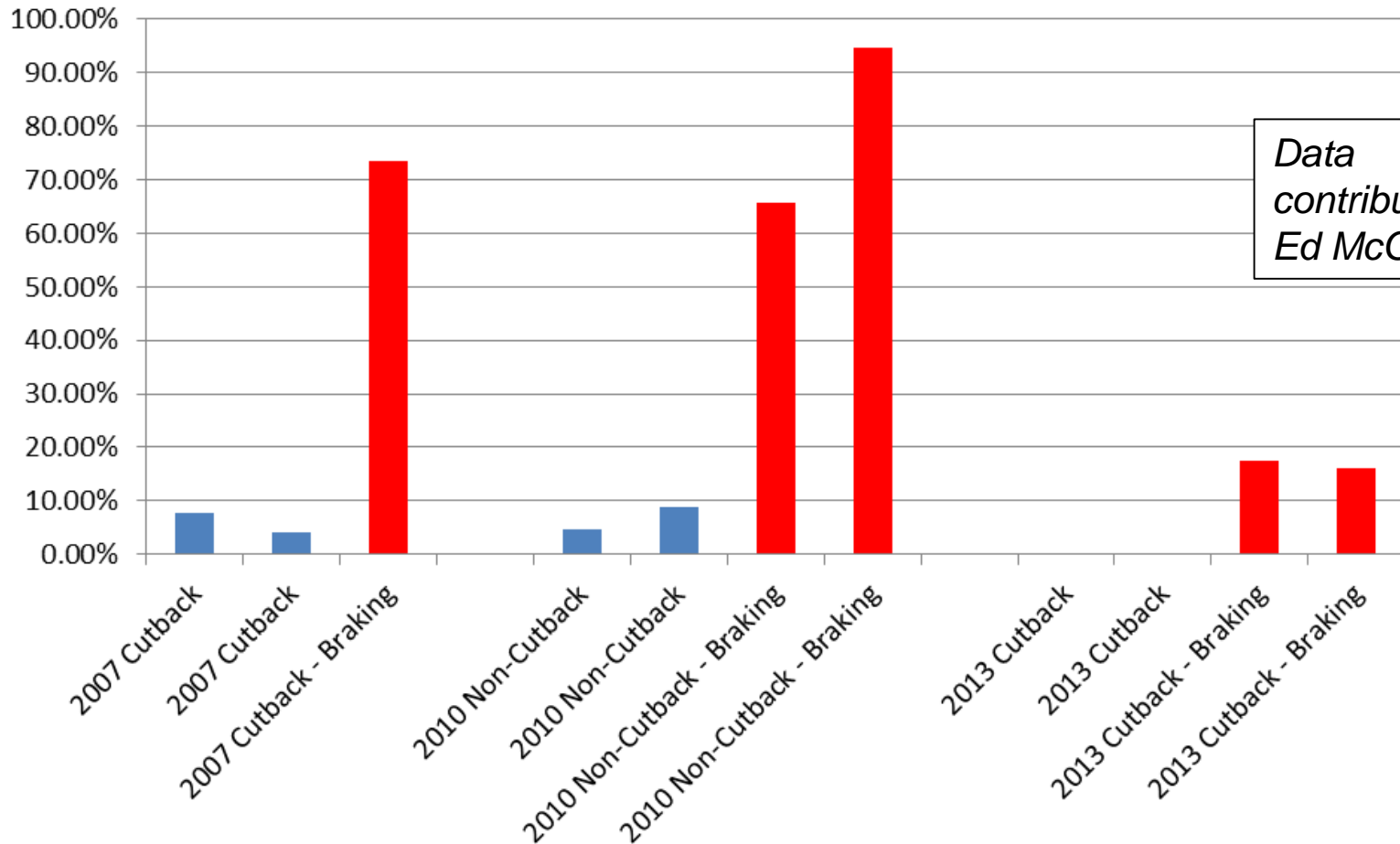


Engine Braking

- Engine Braking will Create a Negative Pressure in the Cylinder
 - The energy that is created during compression is then released out of the exhaust valves.
 - Since all pressure is released, when the piston goes down to the bottom of the stroke it creates a vacuum.
- The Negative Pressure Will Suck Oil Upward
 - (Natural gas engines have this vacuum condition both at idle *and* during engine braking)
- Thus Increasing Oil Consumption and Carbon Packing.

Engine Braking

Effect of Engine Braking Carbon Packing

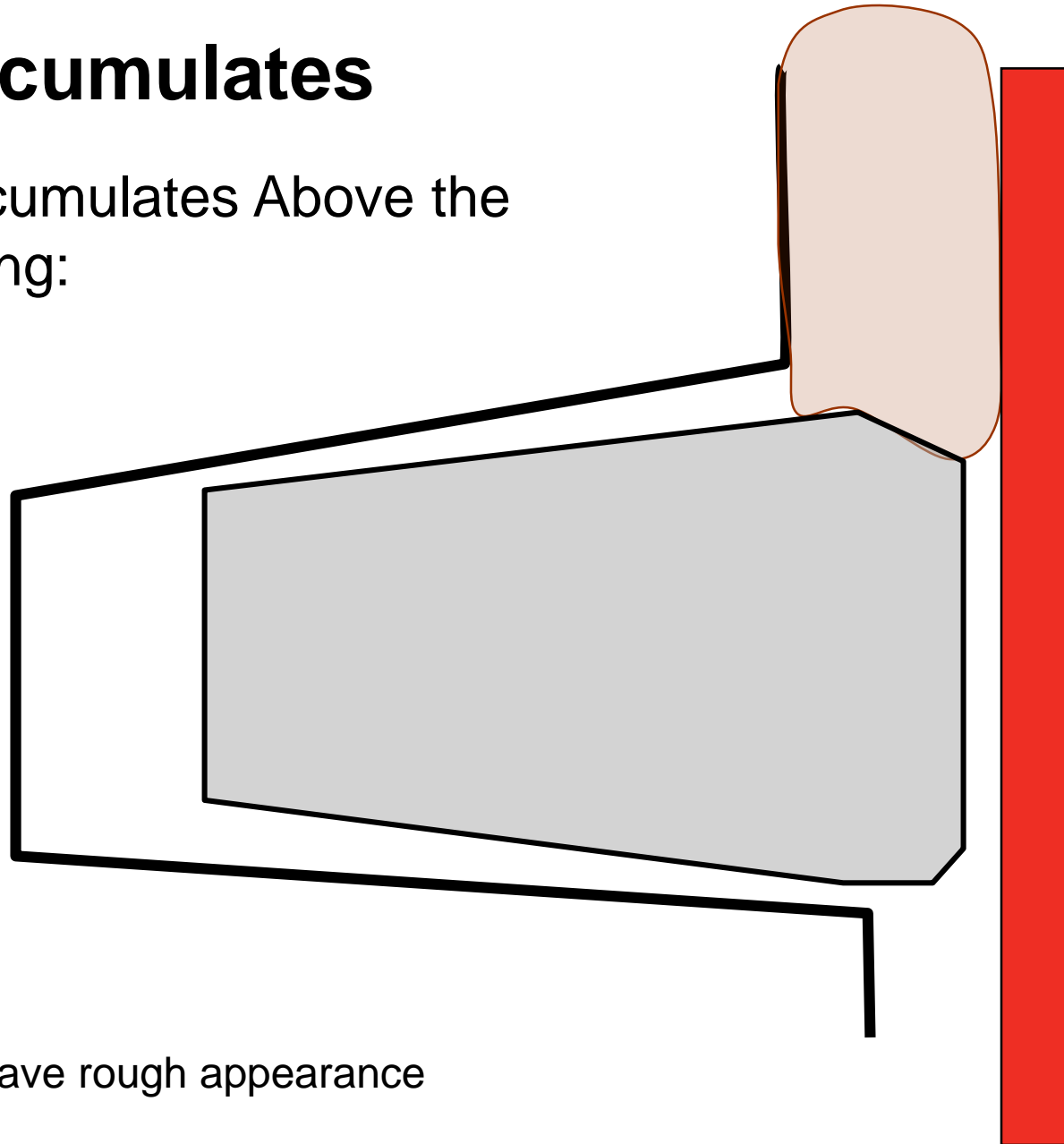


*Data
contributed by
Ed McCullough*



Oil Accumulates

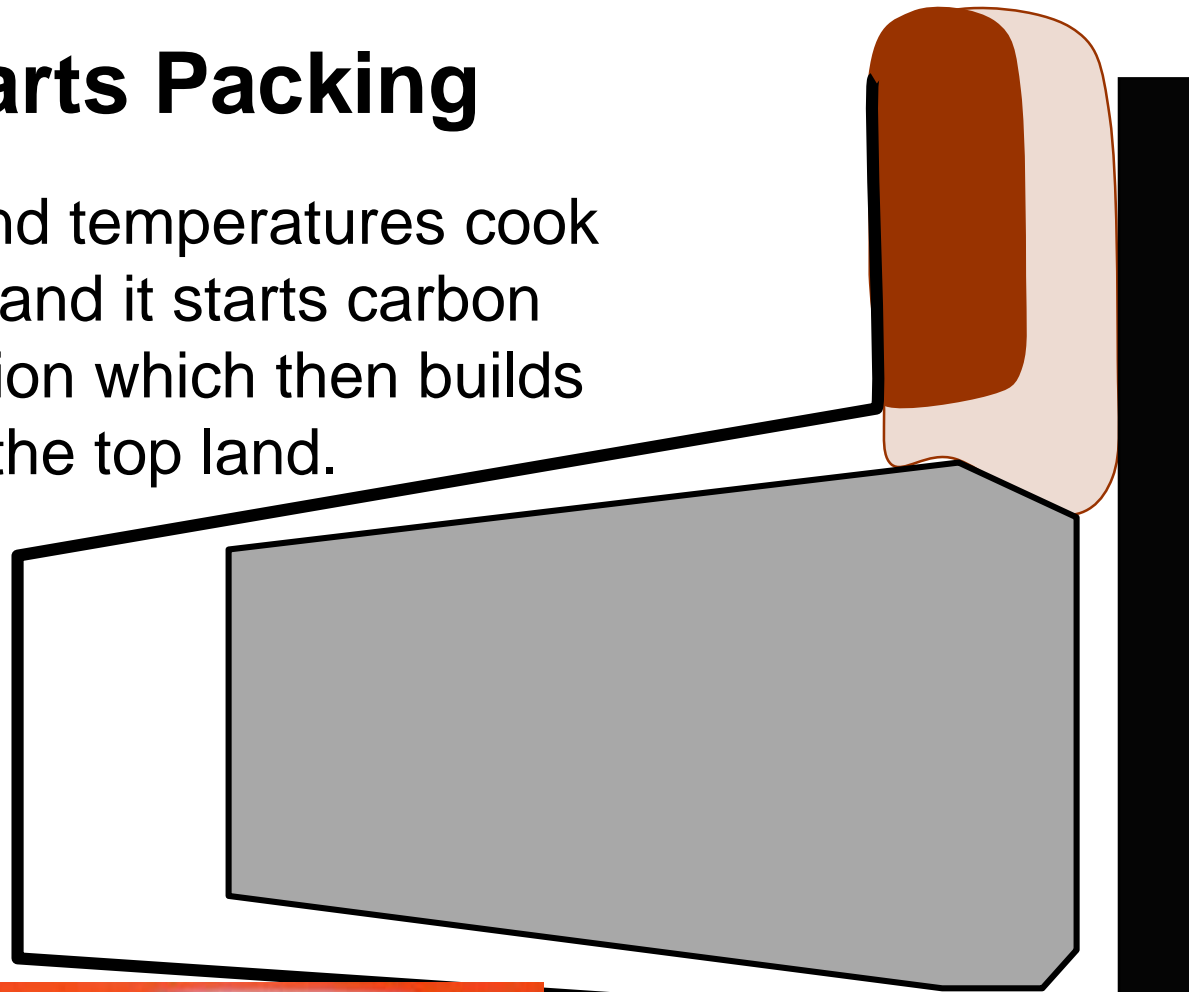
- Oil Accumulates Above the Top Ring:



Will have rough appearance

Oil Starts Packing

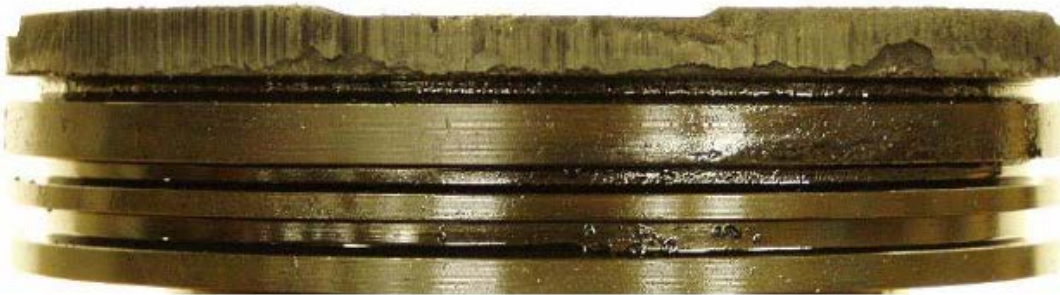
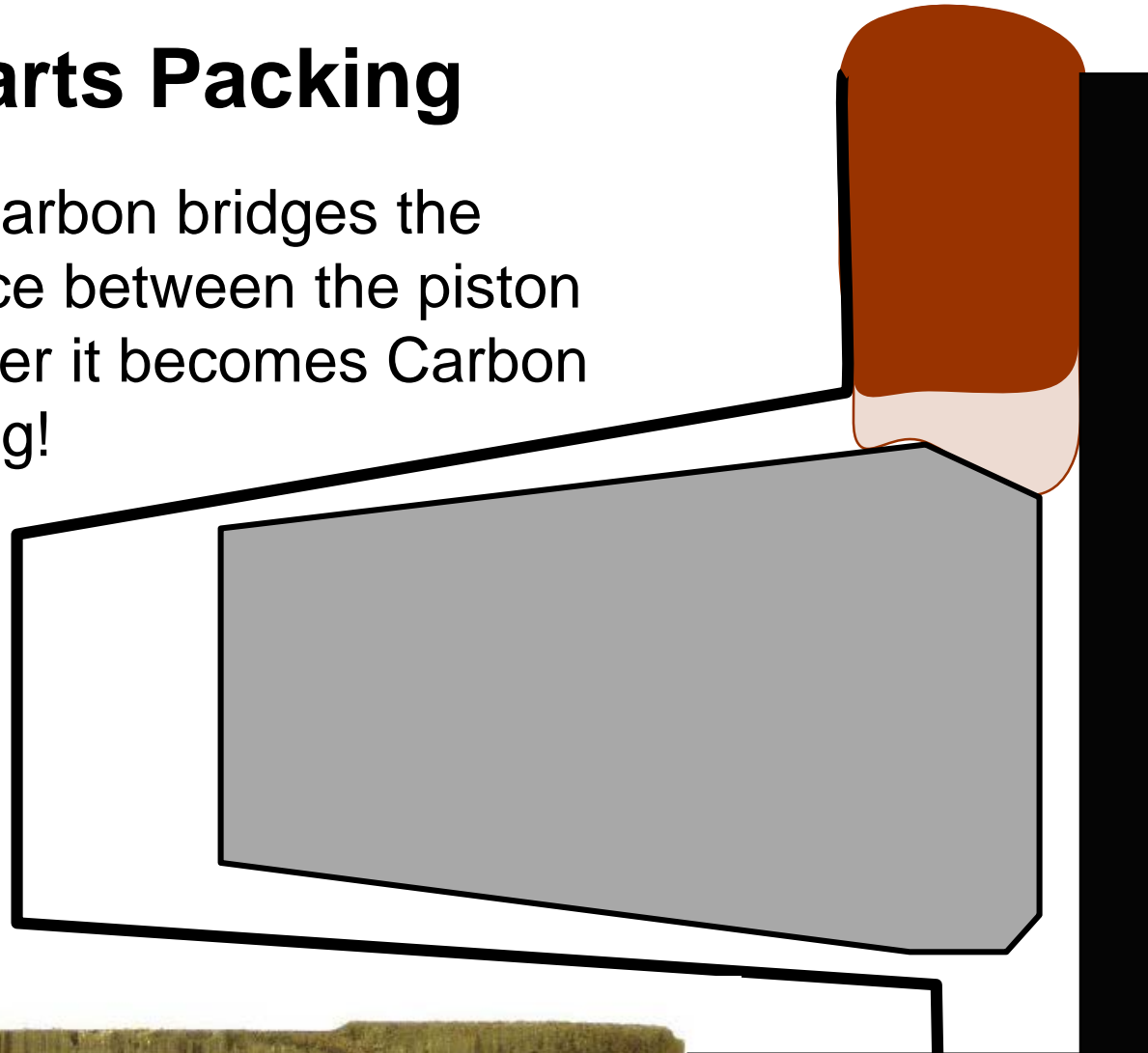
- Top land temperatures cook the oil and it starts carbon formation which then builds up on the top land.



*This is **not** considered “carbon packing” because it does not completely bridge the gap between the top land and the cylinder wall.*

Oil Starts Packing

- If the carbon bridges the distance between the piston and liner it becomes Carbon Packing!

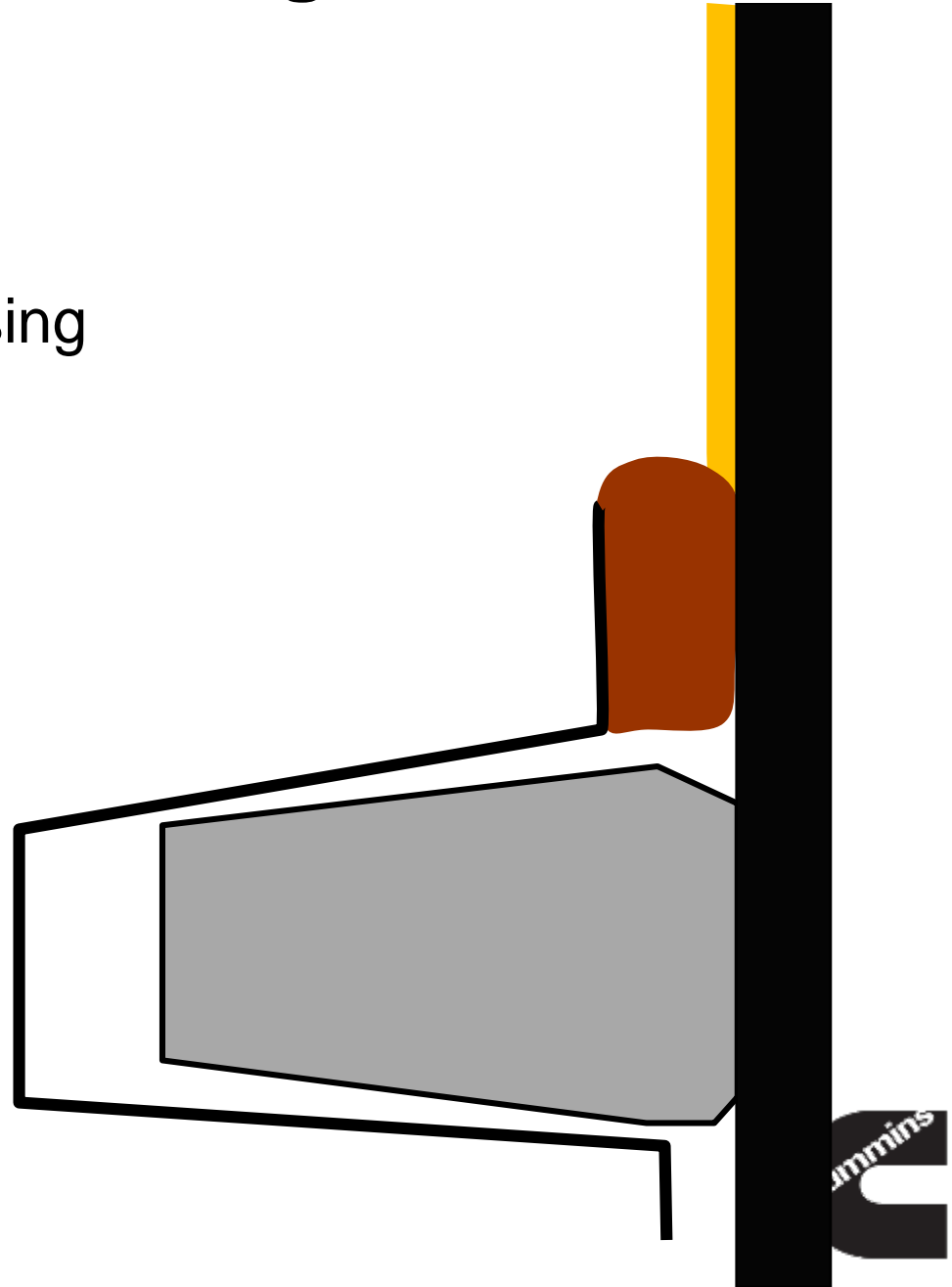


This is “carbon packing” because it the carbon completely bridges the gap between the top land and the cylinder wall.

Effects of Carbon Packing

Theory 1: Oil Scraping

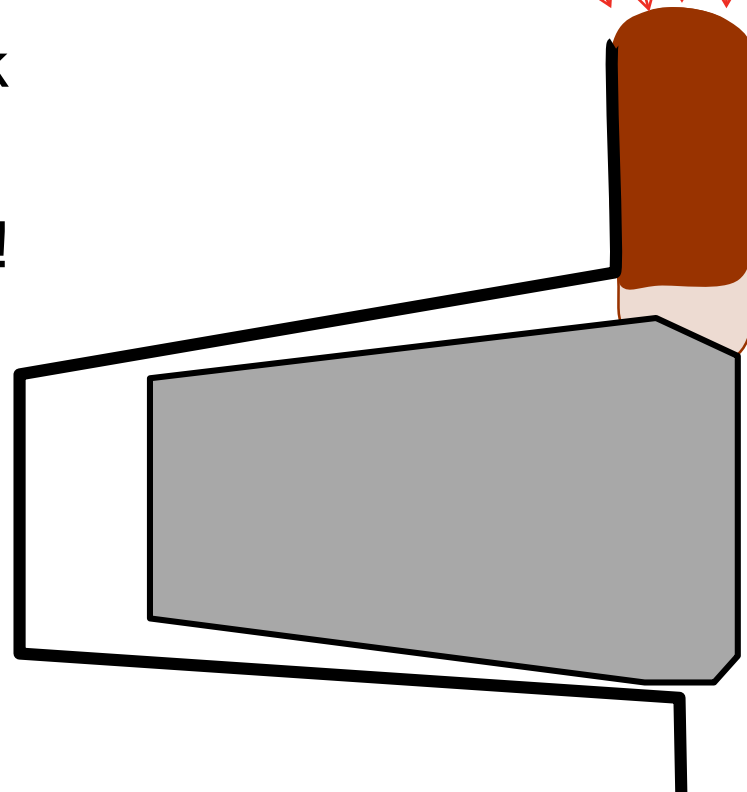
- Carbon Packing may scrape oil upward, causing high oil consumption.



Effects of Carbon Packing

Theory 2: Energizing the Ring

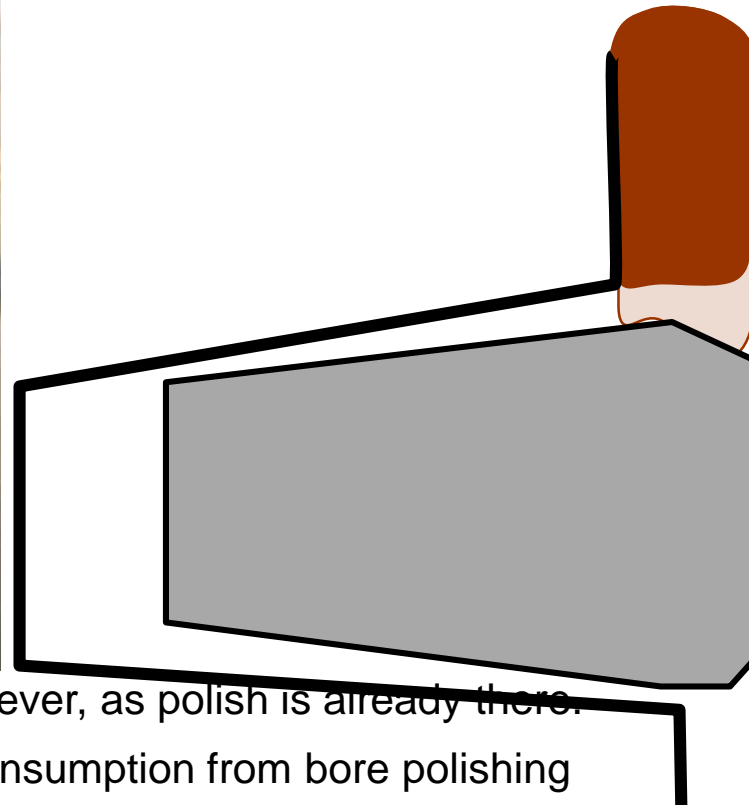
- Carbon can prevent the pressure from getting behind the ring and energizing the ring!
- May affect the ring pack dynamics.
- The Rings Cannot Seal!



Effects of Carbon Packing

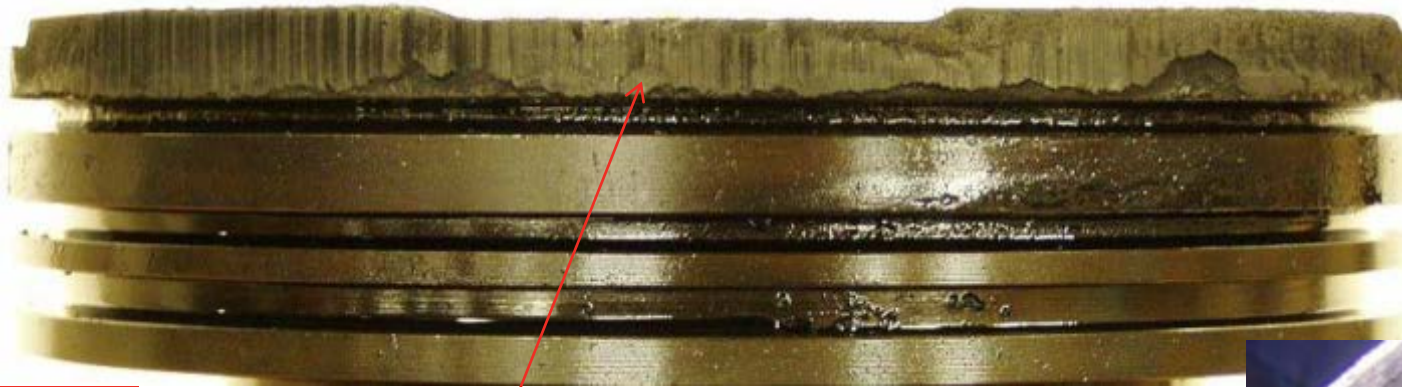
Theory 3: Bore Polish

- Carbon Can Polish the Bores.
As a result, the OC will be high because the rings cannot scrape the bore efficiently.



Cleaning the carbon here would not fix this however, as polish is already there.
Could be up to 100k miles before you see oil consumption from bore polishing though (ISX)

High Oil Consumption Piston and Liner



Carbon Packed
Top Land

Bore Polish
Through Cross
Hatch from Piston
Carbon Rubbing



Piston Carbon Packing

FIXING THE ISSUE:

ELIMINATE THE OIL



Block Oil Going Up

Not certain that you can fix oil consumption with this, it will help, but not eliminate.

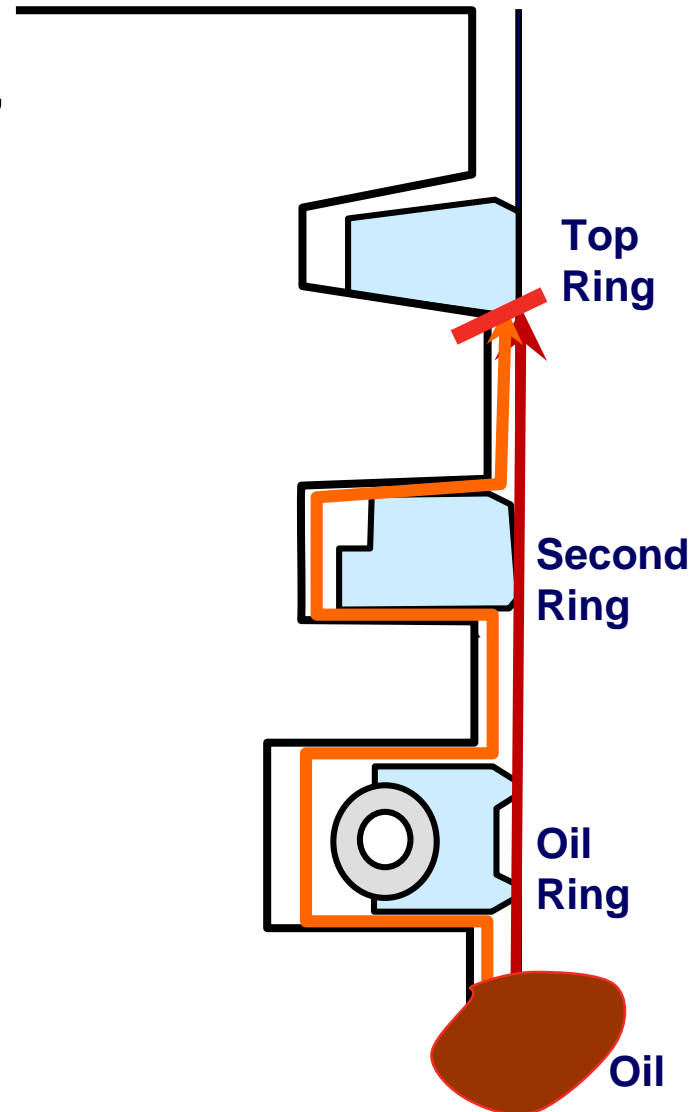
- **Theory**

If no oil gets to the top land, then carbon cannot form.

- **Reality**

There are no perfect seals. Any oil that gets past the rings can cause carbon packing.

It may be impossible to get the OC low enough.



Land cut-backs are not shown here, but can be very important in giving oil a place to drain. Just need to be sure there is enough support for the rings!



Block Oil Going Up

■ Advantages

- Oil consumption will be low
- Good for emissions

■ Way to Reduce Oil Consumption

- See Class on **Oil Consumption**
- Common ways to reduce OC
 - Higher Gas Flow Down (large 2nd ring gap, -Tw ring...)
 - Better Scraping (sharp edges on compression rings, higher pressure oil rings, more conformable rings...)
 - Good Sealing Surfaces (Smoother cylinder bore surface finish, Ring & groove surface finish)
 - Better Valve Sealing



Block Oil Going Down

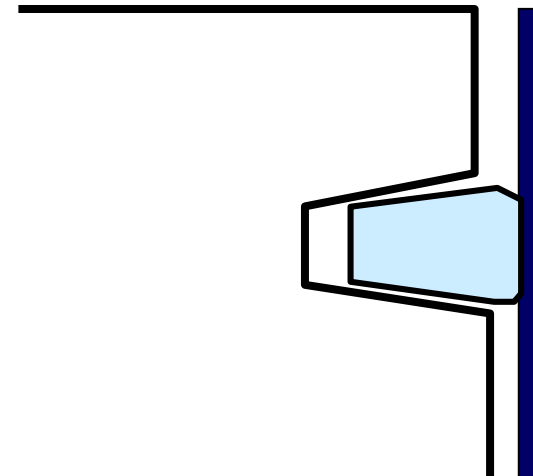
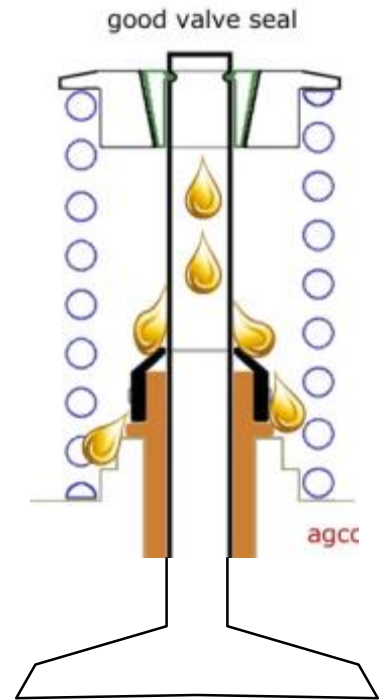
- **Theory**

If no oil gets to the top land then carbon cannot form.

Improving valve stem seals has been shown to help / fix some issues.

- **Reality**

This has fixed top land carbon packing issues in the past.



Block Oil Going Down

■ Advantages

- Oil consumption will be low
- Good for emissions

■ Way to Block Oil Going Down

- Better (drier) valve stem seals
 - Danger: Can cause excessive valve, valve guide, or seat wear.
- Fix damaged valve stem seals (for example during assembly)
- Fix assembly if it is damaging valve stem seals.
- Fix stem seals from coming off

■ Disadvantage

- It is not always possible to reduce the oil past the valve any more.



Piston Carbon Packing

FIXING THE ISSUE:

STOP CARBON FORMING

If you run full power you will burn off the carbon. Keep this in mind as you will likely not see this during development testing.

Temperature

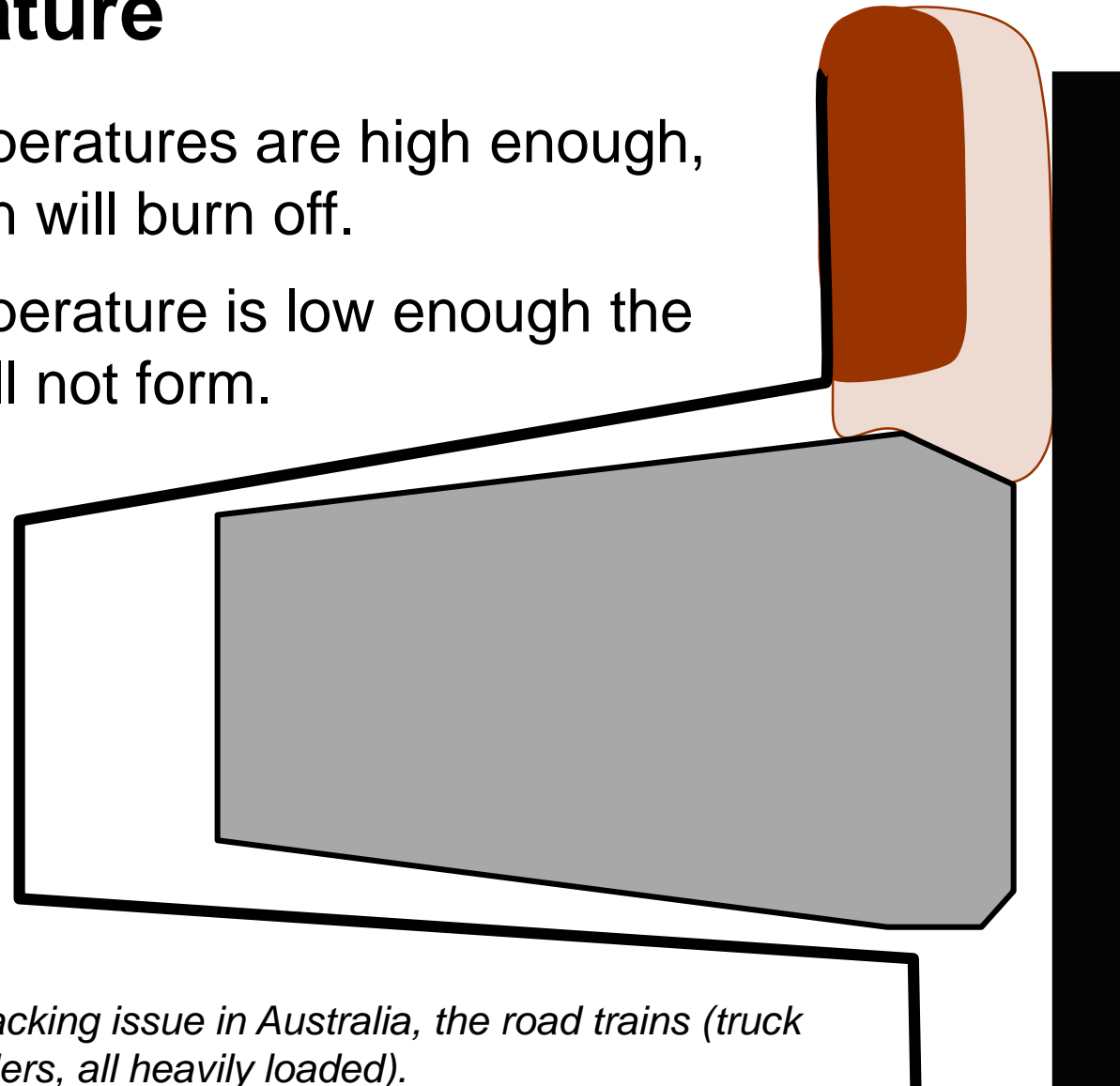
- If the temperatures are high enough, the carbon will burn off.
- If the temperature is low enough the carbon will not form.

Most of our engines run right in the range that forms carbon however.

May not be a real lever.

During carbon packing issue in Australia, the road trains (truck pulling many trailers, all heavily loaded).

Running so heavily loaded they didn't and don't have this problem. Nor do high loaded generators!



Temperature



- Highly loaded applications do not tend to form carbon packing as much as the lighter applications.
 - Large road train trucks in Australia did not form carbon packing
 - However the coolant systems in are designed for the heavy loads. As a result, the engines run cooler than run lighter loads..
 - Carbon packing is very bad on the lighter loaded engines.



Duty Cycle

- Engines with highly cyclic loads tended to have high carbon packing
 - Theory: Oil transfers to the top land during light load. At higher loads it bakes the oil.
 - Example.
 - Engine would load up coal and travel very highly loaded to deliver the coal.
 - The mine is at the top of the mountain. As they went down the mountain, they would use **engine brakes** very heavily.
 - After delivery, it would return unloaded.



<http://www.flickr.com/photos/71125167@N00/3841391577/>



Duty Cycle

- New Engines Bobtailing
 - New trucks (with new engines) would “Bobtail” long distances to their destination.
 - The engine has not been run in so the Oil Consumption would be high.
 - This would allow carbon to build up.



<http://www.motorera.com/dictionary/bo.htm>

Bobtail Trucks



[http://commons.wikimedia.org/wiki/File:Volvo_bobtail_semi-truck_\(LandSpan\).jpg](http://commons.wikimedia.org/wiki/File:Volvo_bobtail_semi-truck_(LandSpan).jpg)

Oil Formulation

- There is some work being done to investigate modern oils that would produce less carbon
- Some oils may prevent carbon packing.
- Cummins doesn't specify synthetic oils, so despite the likelihood those oils would build up less carbon it may not be a solution

Coating on the Top Land

- It is thought that a coating on the top land could be made so that carbon could not stick.
- Currently we do not know of a coating that will work.
- Coating adhesion could be an issue.

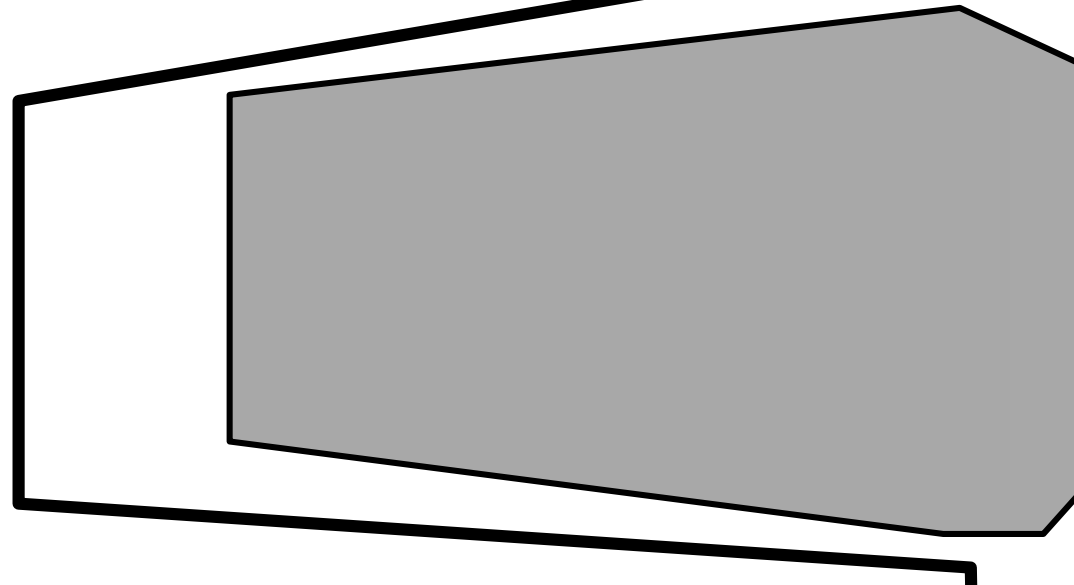
Piston Carbon Packing

FIXING THE ISSUE:

**REMOVE THE CARBON
DURING OPERATION**

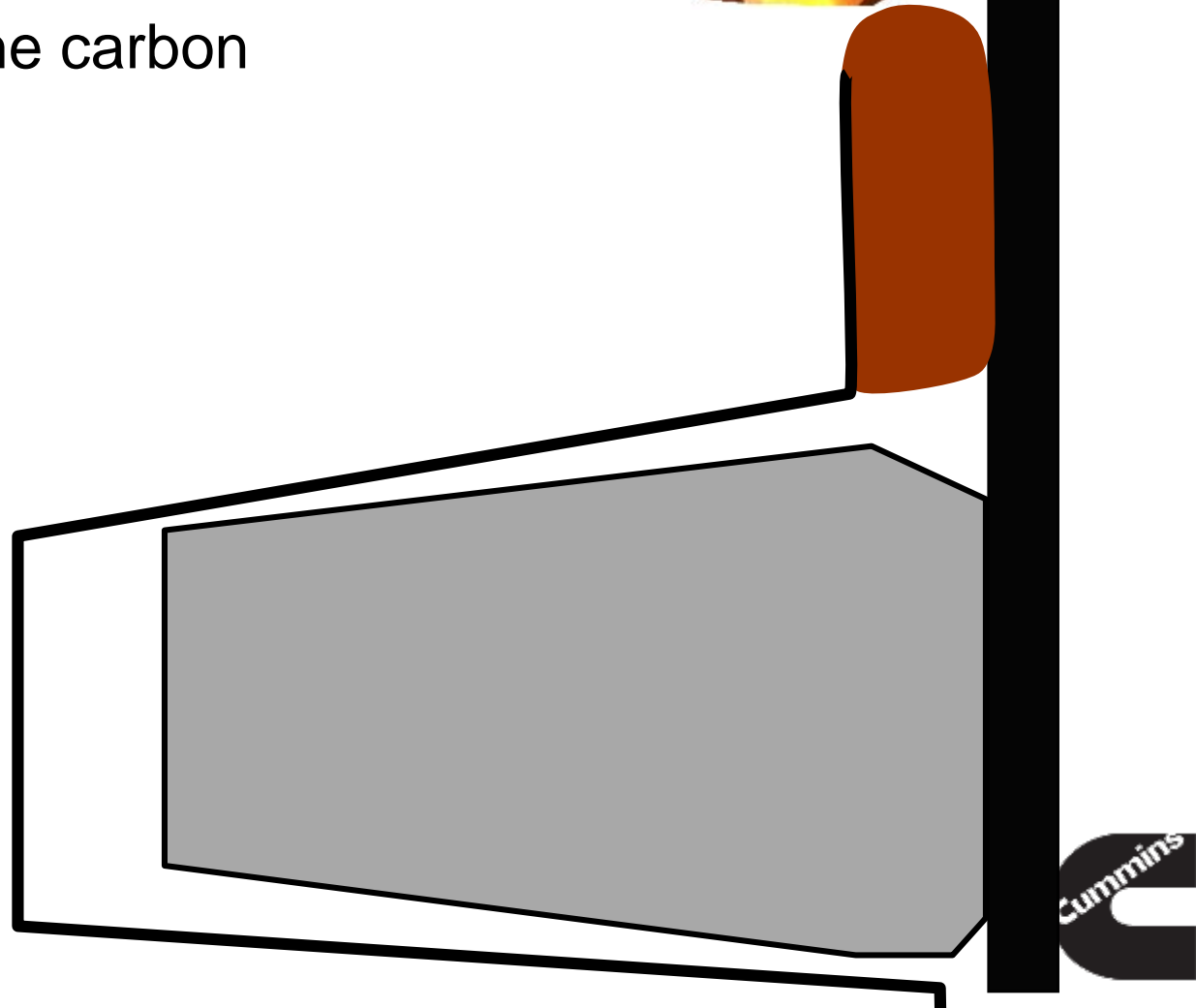
Top Land Cut Back

- If the top land clearance is large enough, then the combustion can burn the carbon.



Top Land Cut Back

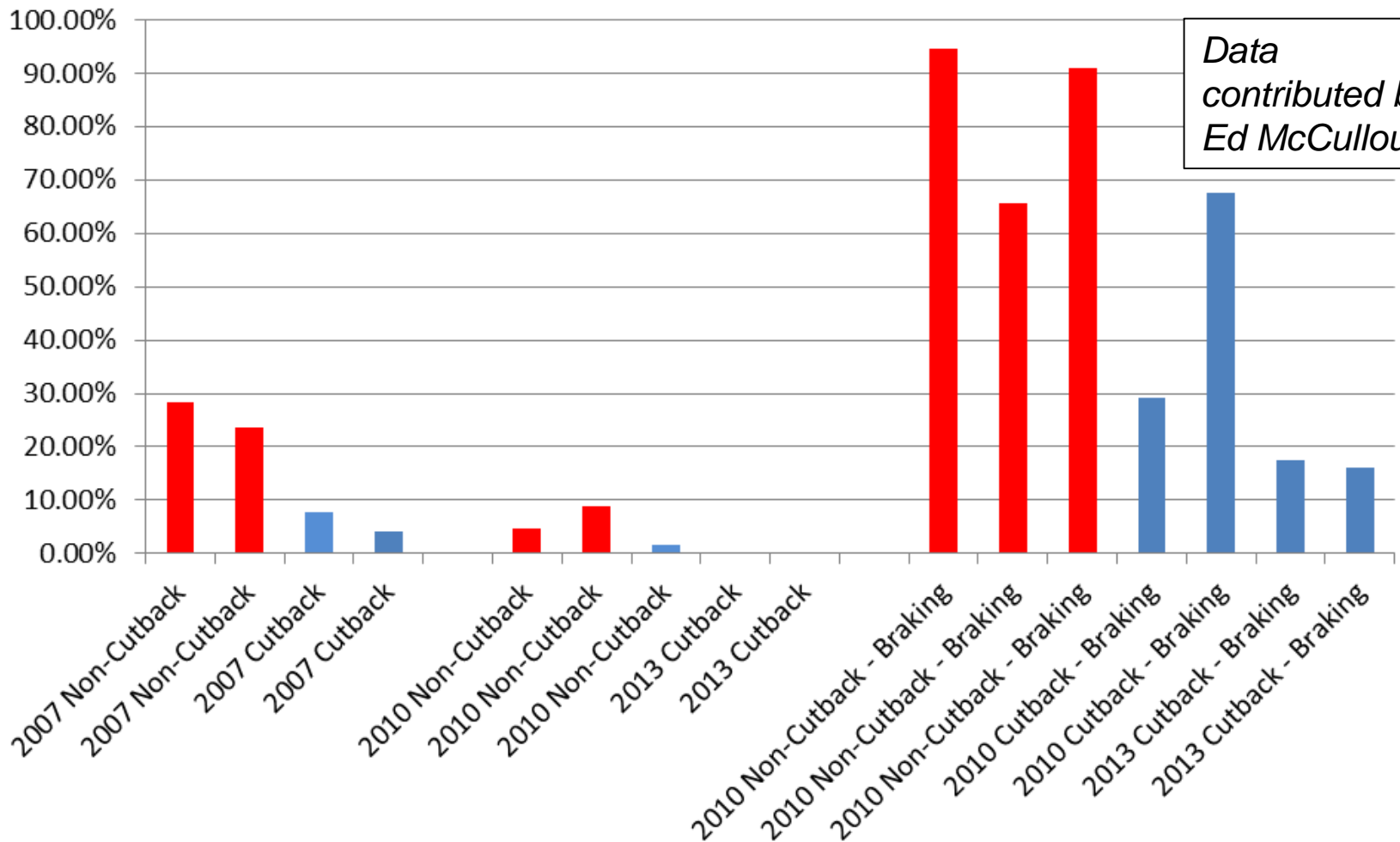
- If the top land clearance is too small enough, then the combustion cannot burn the carbon



Top Land Clearance

Effect of Top Land Cutback on Carbon Packing

*Data
contributed by
Ed McCullough*



Top Land Clearance

- As you increase the clearance on the top land, the carbon packing disappears.
 - JEP study looked at a design starting with small clearance and carbon packing, then ISX went to a tapered land, then increased cut back up to a “magic” clearance, and at that point carbon ceased forming!
 - Other fixes to carbon packing were implemented, fixed some, but then the issue came back in the field.
- This increased top land clearance was found as a fix in 2009 after many failures, and much cost.
 - **However**, the larger top land cut-back is something that CPE is reluctant to implement. Transparent to emissions in some cases, but perhaps not in others... could be measureable noise.
 - Also, during next-gen development testing, carbon packing not found in test cells, so cut-back was not implemented, and failures came BACK!
 - ***NEED TO ALWAYS HAVE THIS CUT BACK***



Top Land Cut-back

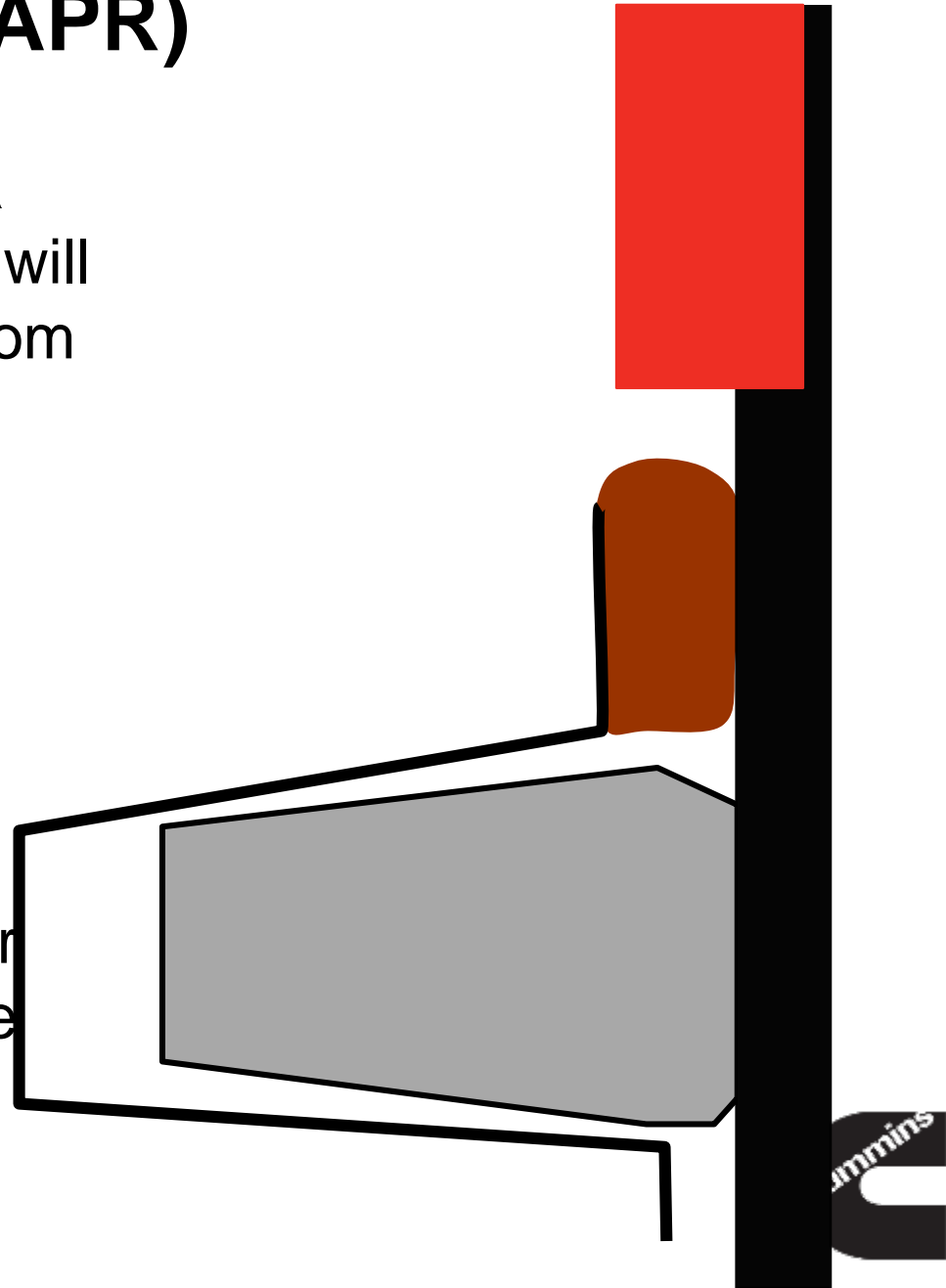
- Top land cut-backs are not a new development.
 - In the past (on NT V28 engines on rail grinders), carbon would build up during the low duty cycle operating time when there was very low heat.
 - Once the engine would go to max power, the carbon that was build up would erode the aluminum piston above the top groove.
 - Once a top land cut back was added the failures stopped.
- Now ESW (Engineering Standard Worksheet) requires the cut back.
- This will ensure future engines will incorporate the cut back.



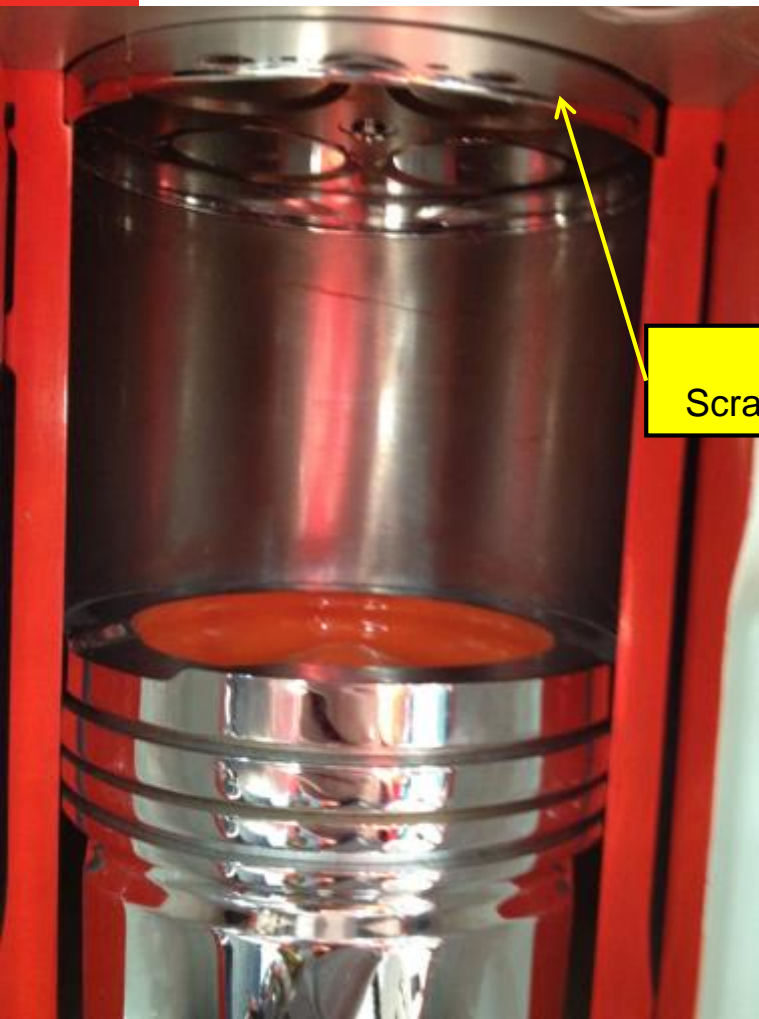
Carbon Scraper Ring

Anti Polish Ring (APR)

- One solution is to add a scraper to the liner that will scrape off the carbon from the top land.
- It is placed above Top Ring Reversal
- Possible Problem: It scrapes carbon down which may cause higher wear of the liner and the top ring face.



2013 Detroit Power Cylinder

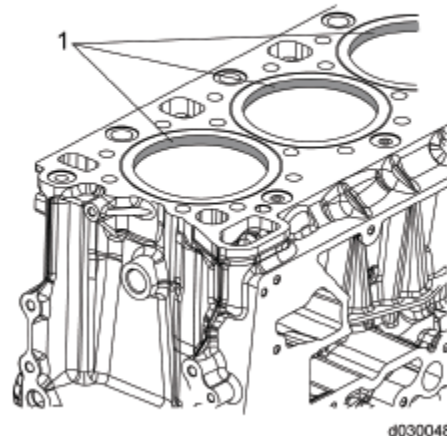


■ Piston Carbon Scraper

- New for 2013.
- Advertised for Fuel Economy and Oil Consumption.
- Expect oil consumption is the main driver.
- Estimated at \$50/engine cost.
- Scania also going this way for all new engines due to oil consumption.

NOTICE: Be cautious not to damage the carbon scraper ring. It will be reused unless it is damaged or the cylinder liner is to be replaced.

6. Use Scotch-Brite® pads to remove any carbon deposits from the upper inner surface (1) of the cylinder liner.

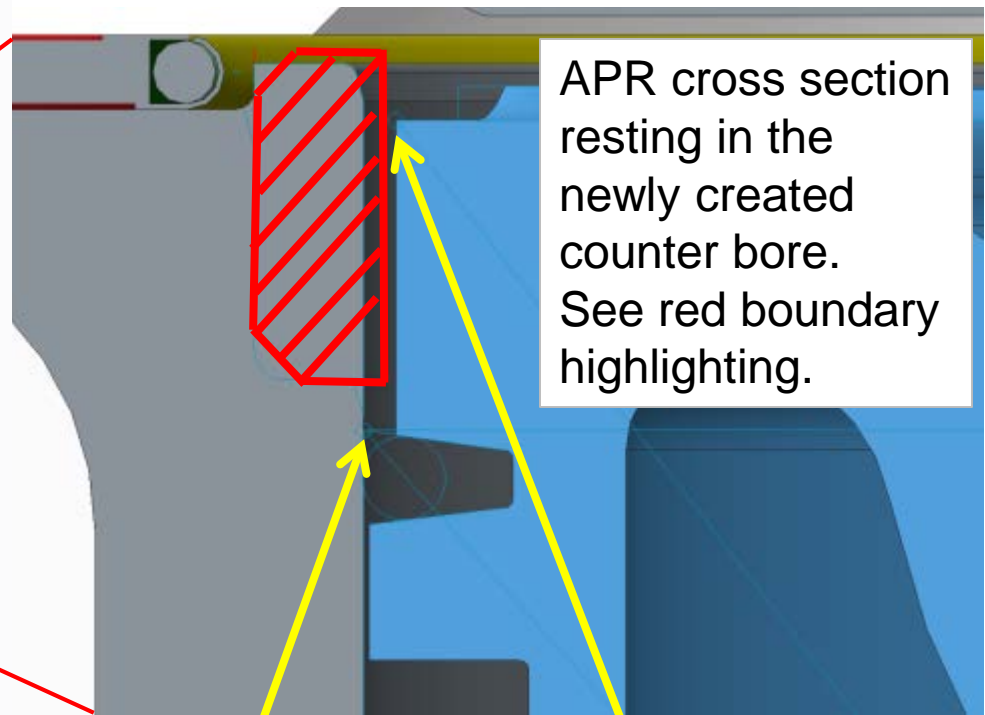
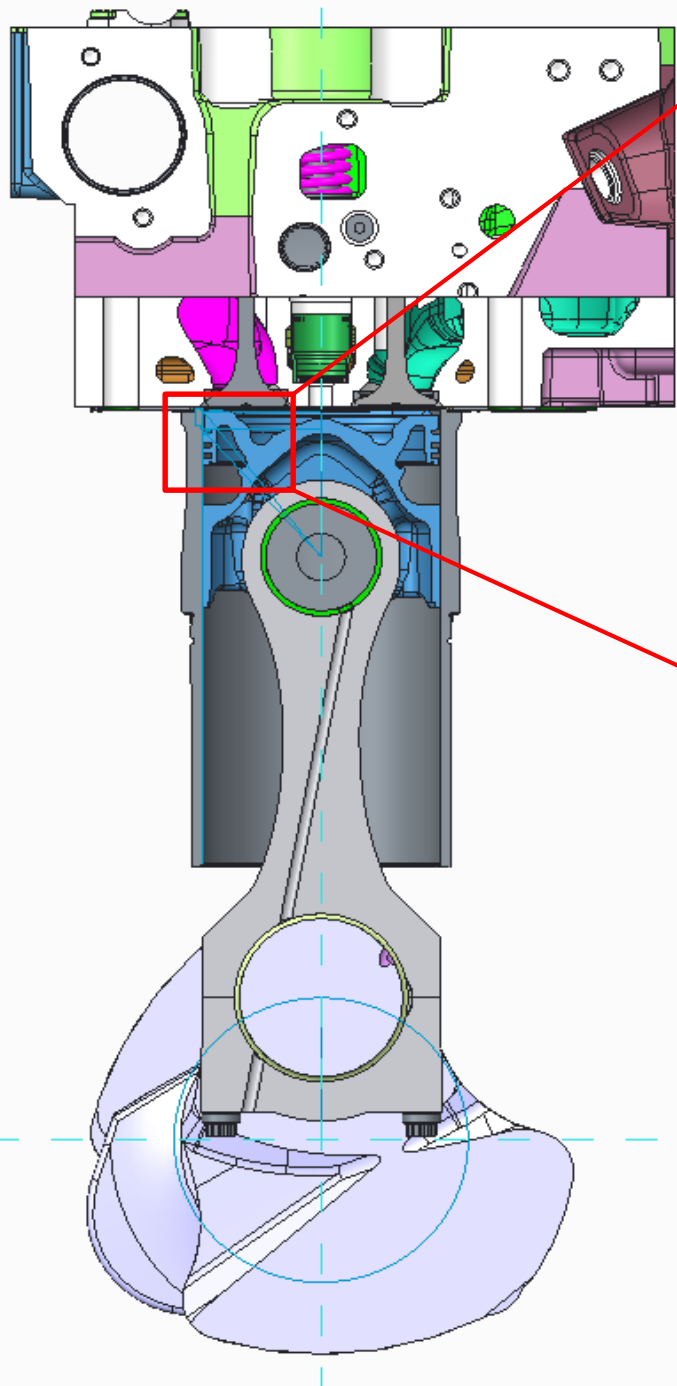


7. For GHG14 engines, remove the Carbon Scraper Ring on the inner diameter of the cylinder liner.
8. Remove the piston oil spray nozzles (1) from the base of the cylinder bores and discard the nozzles.

Common Terms:

Carbon scraper ring

Anti-polishing ring



APR cross section resting in the newly created counter bore. See red boundary highlighting.

Theoretical uppermost extent of ring

Upper corner of piston.

Primary design hurdles for Anti-polishing ring (APR): (Target 8/16/13)

- 1) Avoid top ring to APR contact
- 2) Avoid upper piston corner contact
- 3) **Min clearance = min carbon!**

Piston Carbon Packing

FIXING THE ISSUE:

**REMOVE THE CARBON
AFTER OPERATION**

Water Injection

- A series of tests were run at Cummins and it was determined that by injecting water into the cylinder the carbon could be cleaned off.
- This could be done as a service option to clean the carbon off the top of the piston.
- It is a lot less expensive than rebuilding the engine.

Effect of Water Injection

Water injected thru the intake manifold to clean the carbon off the top of the piston.

Contributed by
Brian Seibert



Vs.



Water Injection Verification Test #1

Post Test Carbon Measurements

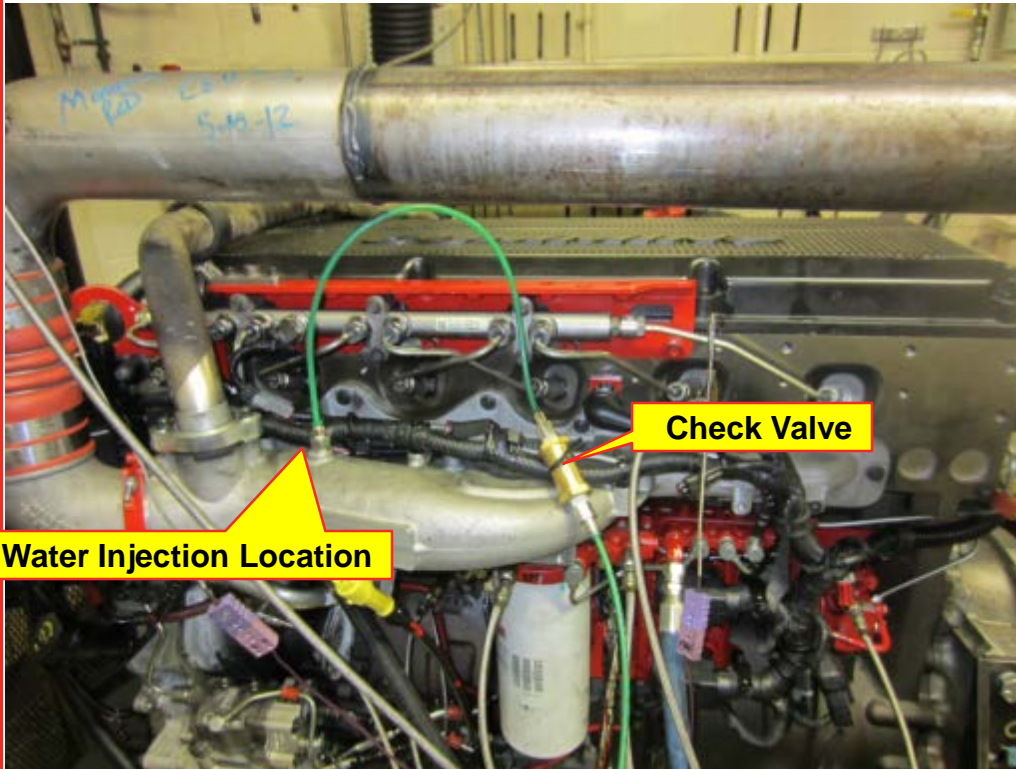
		A	B	C	D	E	F	G	H	Total (cm)	% Circ	Improvement
Piston	C1	0.00	0.00	0.00	0.50	0.00	0.30	0.00	0.00	0.80	2%	96.2%
	C2	0.40	1.20	0.30	0.00	0.00	0.00	0.00	0.00	1.90	4%	93.2%
	C3	0.80	0.40	1.30	1.50	2.40	0.60	0.00	0.50	7.50	17%	77.1%
	C4	0.00	0.00	0.00	1.60	0.00	0.00	0.30	1.00	2.90	7%	86.3%
	C5	0.00	0.00	0.80	2.20	0.30	0.00	1.10	2.40	6.80	16%	76.5%
	C6	0.00	0.00	0.00	0.00	0.00	1.00	1.70	2.50	5.20	12%	82.7%
										25.10	10%	84.5%

84.5% reduction in piston top land carbon packing

Contributed by
Brian Seibert



Water Injection Setup

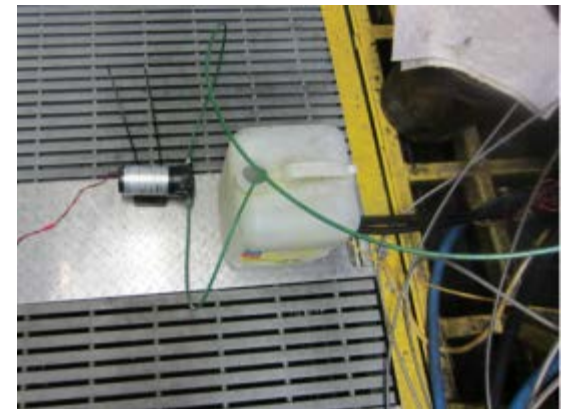


Water injection nozzle sized for 3.3 GPH flow rate



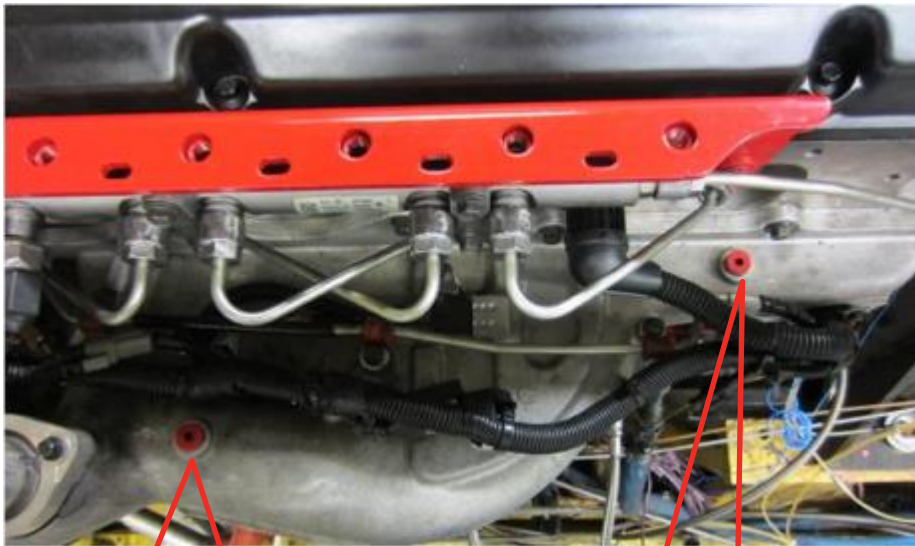
12V Pump

Pumps water at 200psi from a 4 gallon supply bucket.



Contributed by
Brian Seibert

Water Injection Setup



Contributed by
Brian Seibert

Additional Steps:

1. Plumb boost pressure switch into the intake manifold port 2 as a **failsafe against water injection while engine is not running**.
2. Disconnect crankcase breather inlet hose. Route hose from valve cover or gear housing fitting into a bucket.
3. Disconnect the after treatment at the inlet fitting and direct exhaust flow in a safe direction into a vent.

Water Injection Dangers

- The combustion process creates a lot of water but it does not damage the cylinders because it is a vapor that leaves through the exhaust.
- Watch Outs
 - Keep the water vaporized
 - Ensure all water injected is removed
 - Prevent the parts from rusting
 - Prevent liquid water in the cylinder that may cause hydro-lock.
 - Ensure good water distribution through the cylinders
 - Have good service practices to ensure the above.



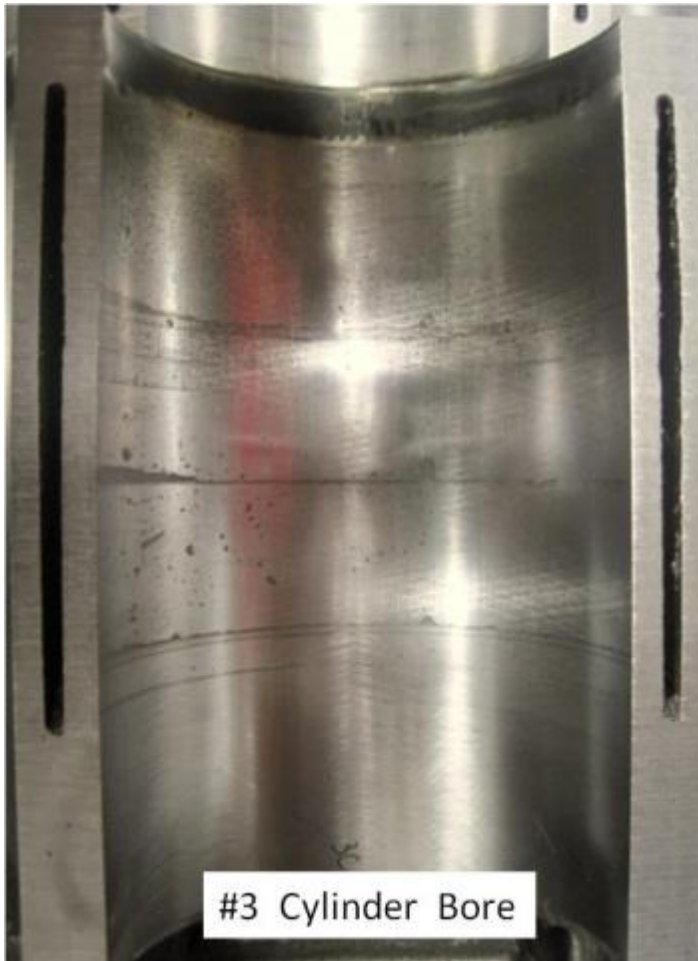
Water Injection

- A series of tests were run at Cummins and it was determined that by injecting water into the cylinder the carbon could be cleaned off.
- You would have to keep the water in vapor for during this service operation
 - Concern if not kept in vapor, could hydro lock or rust!
- Many open questions that are being evaluated
 - How long would this procedure need to be done?
 - How frequently?
 - How to control the process appropriately?
 - Etc...

Water was able to get in engine (intake), then sat for ~ 1 year.

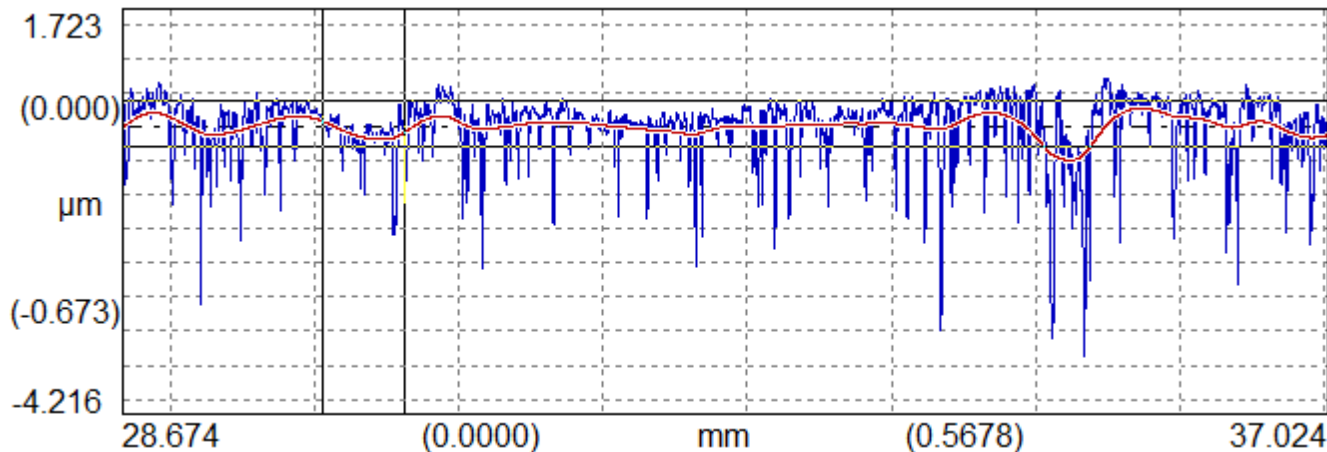
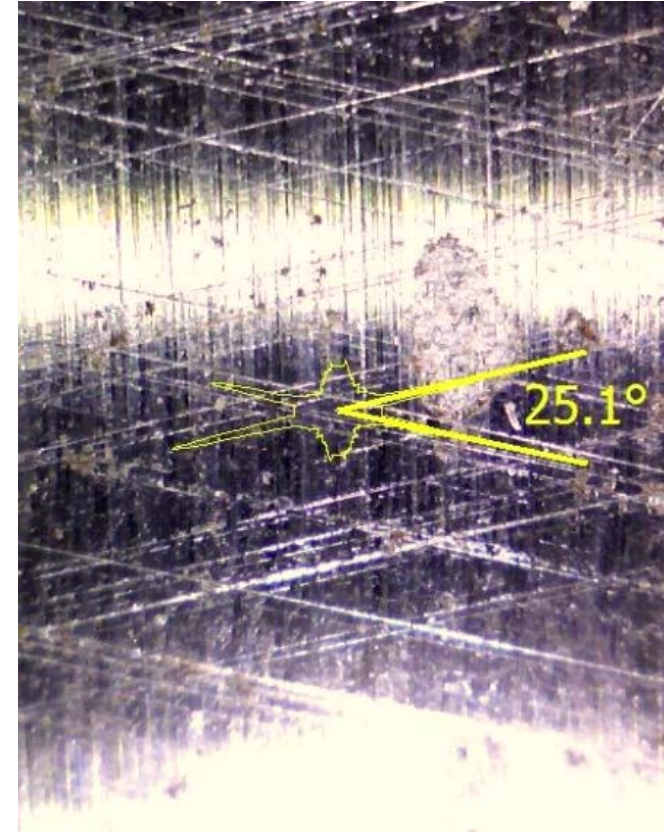
Rusted Cylinder Bores

- Rust in the cylinder correlated with very high piston ring wear *Engine was built, not needed right away. Stored, but not correctly (not sealed up correctly!)*



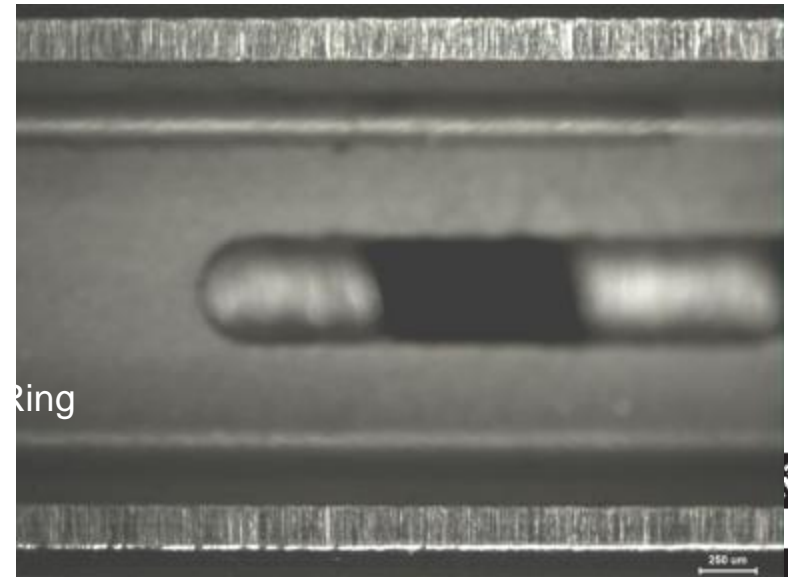
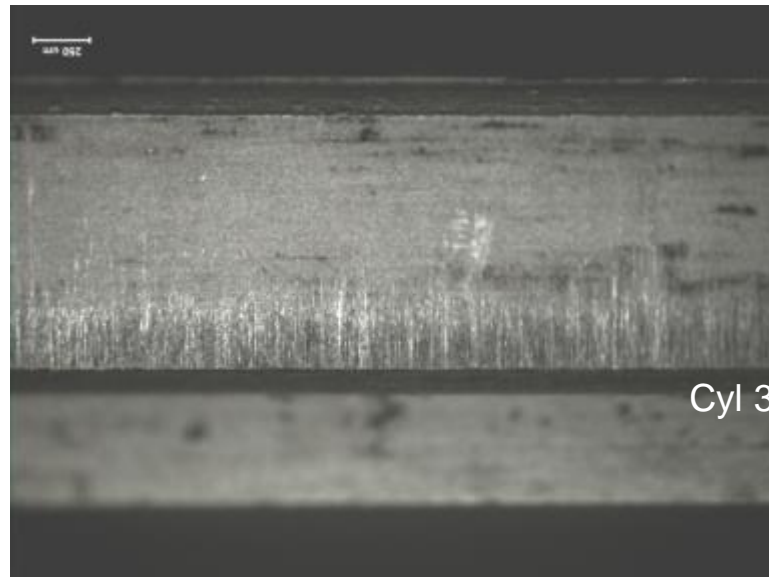
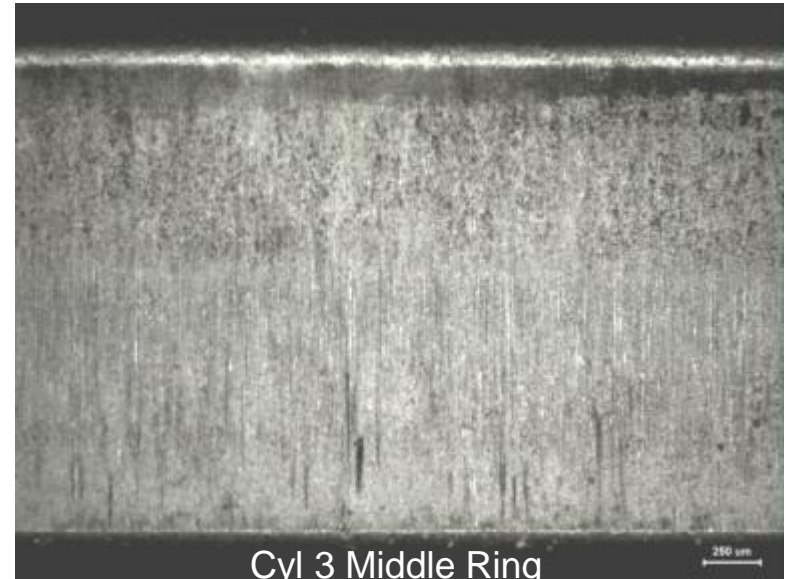
Rusted Cylinder Bores

- Rust creates holes in the cylinder
- It is thought that the holes in the liner caused by the rust resulted in excessive ring wear.



Rusted Cylinder Bores

- These photos show the extreme wear to the rings caused by the rust in the cylinder bores.



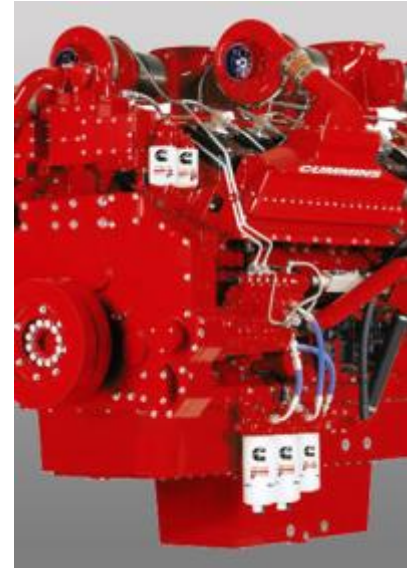
Piston Carbon Packing

FIXING THE ISSUE:

**COVERING ALL FAILURE
MODES**



ISX15 Liner Lobing



15L Liner Lobing

- **Problem Description**

- ***Customer Complaint***

- –Oil consumption
- –Aftertreatment frequent regen faults
- Early life complaint < 120K miles (2000hrs)

- ***Cause***

- Liner has a 13 vertical lobe pattern that the piston rings do not conform to. This allows unscraped oil to pass into the combustion chamber and be consumed. This condition will also accelerate piston carbon packing.

- ***Start of Problem*** - Unknown at this time

- ***End of Problem***

- Liner manufacture changed to 9 tooth bore cutter
- •Liners cut from new tooling will be date coded **284 3 1** (**284th** day, 2013, **1st** shift)



Correlation to carbon packing is still under investigation



Liner Identification Date Codes

- GKN USA Liner
- –Date code located on the liner combustion seal seat
- •**138 2 3** = Day 138 - 2012 – 3rd shift = May 18th 2012 3rd shift
 - Date codes are difficult if not impossible to see on a used liner. This reference is for new liners.



- If failures are being seen where fixes or countermeasures have already been implemented, please follow normal escalation process for technical escalation.
 - DFSE involvement (Distributor branch level)
 - DTS/DFSE (Dealer level)
- These failures need to be identified and reported to a Factory level for in-depth analysis so that further testing and project work can take place if necessary.