



DD13 Scuffing Test Latest Results and Procedure

5-7-13

- Current Procedure
- Current Hardware
- Test Results
- Additional Analysis
- Next Steps



Detroit Diesel Message



Current Procedure

Procedure



- Test Length
 - 200HR
 - § Subject to change. Target is closer to 100 hours.
- Hot Soak
 - 1 Hour Soak every 25 hours
 - § 24HR run / 1HR soak to make 25HR segments
- Multiple Power Levels
 - 0-25HR = 50% throttle
 - 25-75HR = 75% throttle
 - 75-200HR = 100% throttle
- 25 Hour sample intervals
 - Sample taken at idle following soak

Potential P/F Parameters



- **Piston Ring / Cylinder Liner Scuffing**
 - % scuffing on liner
- **Top Ring Weight loss**
 - Could be a ring gap measurement also
- **Connecting Rod Bushing Wear**
 - Working on measurement procedure with Detroit
 - Visible wear has been seen
- **Rocker Arm Bushing Wear**
 - Working on measurement procedure with Detroit
 - Visible wear has been seen
- **Rocker Shaft Wear**
 - Working on measurement procedure with Detroit
 - Visible wear has been seen
- **Cam Wear**
 - Working on measurement procedure with Detroit
 - Not much wear seen so far
- **Main Bearing Weight loss**
 - Minimal wear
- **Rod Bearing Weight loss**
 - Minimal wear
- **Piston Rating**
 - Deposits
 - 2nd Land scratching (haven't seen yet)

Operational Specifics (1 of 4)



	Step	Time (min:sec)	Total Time (hr:min:sec)	Speed (RPM)	Speed Ramp (min:sec)	Torque (Nm)	Torque Ramp (min:sec)	Throttle (%)	Throttle Ramp (min:sec)	Coolant Pressure (kPa)
Warm-up	1			600		<i>Throttle Controlled</i>		0		70 ± 3
	2	10:00	00:30:00	1800	08:00	1200	08:00	<i>Torque Controlled</i>		
	3	05:00		1800		1800	03:00	<i>Torque Controlled</i>		
	4	10:00		1800		2032	03:00	<i>Torque Controlled</i>		
	5	05:00		600	05:00	<i>Throttle Controlled</i>		0	05:00	
1	02:00	*23:45:00		600		<i>Throttle Controlled</i>		0		
2	15:10		1800	00:10	<i>Throttle Controlled</i>		**	00:10		
3	02:20		900	00:10	<i>Throttle Controlled</i>		35	00:10		
4	02:20		600	00:10	<i>Throttle Controlled</i>		0	00:10		
5	21:00		1100	00:10	<i>Throttle Controlled</i>		**	00:10		
6	28:00		2000	25:00	<i>Throttle Controlled</i>		**			
7	04:00		1800	02:00	<i>Throttle Controlled</i>		**			
8	00:10		600	00:10	<i>Throttle Controlled</i>		0	00:10		
Cool Down	1	15:00	00:15:00	600	15:00	<i>Throttle Controlled</i>		0	15:00	
			* each cycle is 1hr 15min				** Varies depending on test hours			
							0-25 = 50%			
							25-75 = 75%			
							75-200 = 100%			

Operational Specifics (2 of 4)



	Step	Time (min:sec)	Total Time (hr:min:sec)	Intake Air Temperature (°C)	Coolant Outlet Temperature (°C)	Fuel Temperature (°C)	Exhaust Back Pressure (kPa)	Exhaust Back Pressure Ramp (min:sec)	CAC Delta Pressure (kPa)	Intake Air Restriction (kPa _{vac})	Intake Air Restriction Ramp (min:sec)	CAC Out Temperature (°C)										
Warm-up	1			25	60	38	0		1	0.5		60										
	2	10:00	00:30:00	35	110	38	10	02:00	6	1	02:00	73										
	3	05:00					20	02:00	10	3	02:00	73										
	4	10:00					30 ± 1	02:00	12 ± 1	3 ± 1		73 ± 2										
	5	05:00					<p style="text-align: center;"><i>Controller voltages locked at end of Step 4 of warm-up. Voltages will be reset following any warm-up event during the test.</i></p>															
Test	1	02:00															*23:45:00	35 (varies)	110 (varies)	38 (varies)		
	2	15:10																				
	3	02:20																				
	4	02:20																				
	5	21:00																				
	6	28:00																				
	7	04:00																				
8	00:10																					
Cool Down	1	15:00	00:15:00	25	80	38	0	00:00	1	0.5	00:00	60										
			* each cycle is 1hr 15min																			

Operational Specifics (3 of 4)



Control Points During Test Cycles

Intake Air Temperature	Coolant Outlet Temperature	Fuel Temperature	Coolant Pressure
35 °C	110 °C	38 °C	70 kPa

Key Non-Controlled Parameters During Cycling

Oil Gallery Temperature	Oil Sump Temperature	Intake Manifold Pressure	Exhaust Temperature
110-120 °C	110-120 °C	0-255 kPa	250-520 °C
Fuel Flow	Oil Gallery Pressure	Intake Manifold Temperature	Oil Consumption
3-77 kg/hr	115-480 kPa	45-100 °C	< 35g/hr

Max Power	385kW @ 1800rpm/2045Nm (510hp)
Max Torque	2450Nm @ 1100 rpm

EGR is feed forward control. Based on Engine Speed and Fuel Mass.

Idle	600 rpm and no throttle
Exhaust Back Pressure	Tailpipe Pressure
CAC Delta Pressure	Turbo Outlet Pressure - Intake Manifold Pressure
CAC Outlet Temperature	Charge Air Cooler Outlet Temperature
Intake Air Restriction	Restriction at turbo inlet
Intake Air Temperature	Temperature at turbo inlet
Coolant Outlet Temperature	Coolant Temperature at engine outlet
Fuel Temperature	Inlet Fuel temperature

Operational Specifics (4 of 4)



	Step	Time (min:sec)	Duration (hr:min:sec)	Notes	Analyticals		
					Test Hour	Description	
Warm-up	1		00:30:00	- Step 1 (idle) time should be minimized. - Samples are taken at Step 1. - This warm-up is used following any shutdown.			
	2	10:00				NEW FUEL	Sulfur/Gravity
	3	05:00				EOT FUEL	Sulfur/Gravity
	4	10:00					TGA Soot
	5	05:00					100KV
Test	1	02:00	25:00:00	- If a shutdown occurs during the cycle restart at Step 1 following warm-up. - Cycle will repeat for 23hrs 45min			
	2	15:10				NEW, 25, 50, 75, 100, 125, 150, 175, 200EOT	40KV
	3	02:20					150HTHS
	4	02:20					100HTHS
	5	21:00					IR oxidation
	6	28:00					ICP
	7	04:00					TBN
	8	00:10					TAN
Cool Down	1	15:00		- Turn off engine at end of cooldown to begin soak - Same cooldown is used for any shutdown			
Soak	1	60:00		- Restart engine at end of soak and procede to warm-up			
This is one 25HR segment of test							

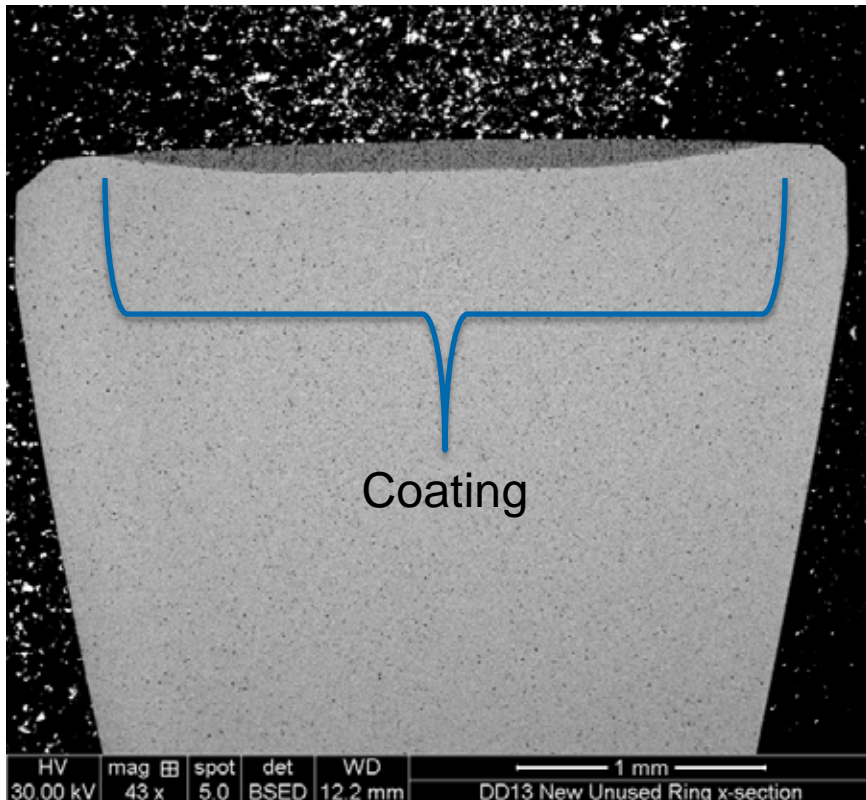


Current Hardware

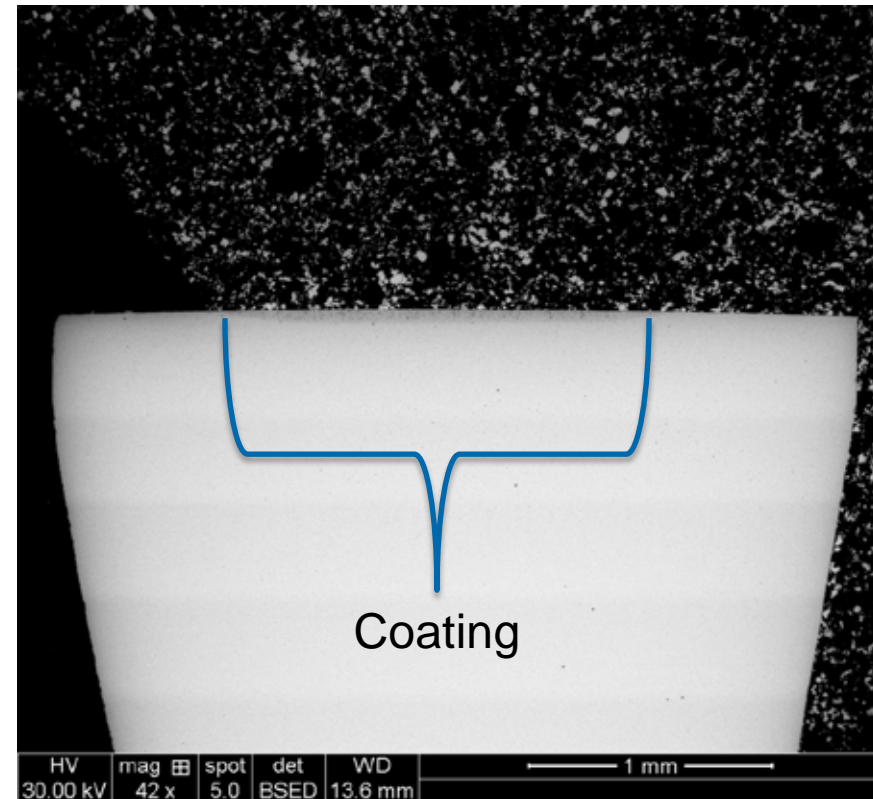
- Cylinder Liners
 - Current production w/ carbon scraper ring
- Pistons, Connecting Rods, Main/Rod Bearings, Camshafts, Rocker Assembly
 - Current production
 - Main/Rod Bearings could change to softer tri-metal construction
- Piston Rings
 - Current production 2nd/Oil ring
 - Top Ring is a special part made with no coating (all steel)

Ring Analysis

New Production Ring



Production ring w/ 716,000 miles



As the Top Ring wears in an engine the amount of coating decreases. Hence the contact area of steel to steel increases. The uncoated top ring for test is simply used to help accelerate the normal wear process.



Test Results

Test # 1 - “Poor” 2.9HTHS



- Test ran 39 hours (EOT sample was not taken do to mis-communication)
 - No shutdowns
 - Scuffing started with 75% throttle
- Scuffing was seen on Cylinder #4
 - Test was stopped immediately after Crankcase Pressure rise
 - § Likely why only 1 cylinder was scuffed
 - § DDC advised to run until at least 3kPa on following tests
- “Poor” 2.9 HTHS
 - An oil based upon a fully formulated CJ-4 DI platform formulated with characteristics of oils which Detroit has seen adhesive wear concerns with certain hardware and engine calibrations in testing.

Test # 2 – 15W-40 CJ-4



- Test ran 137 hours
 - Scuffing began at 129 hours following a shutdown
- Scuffing was seen on cylinders #1 and #6
- 15W-40 CJ-4
 - Oil is a fully formulated commercially available oil with CJ-4 and OEM credentials

Test # 3 – “Good” 2.9HTHS



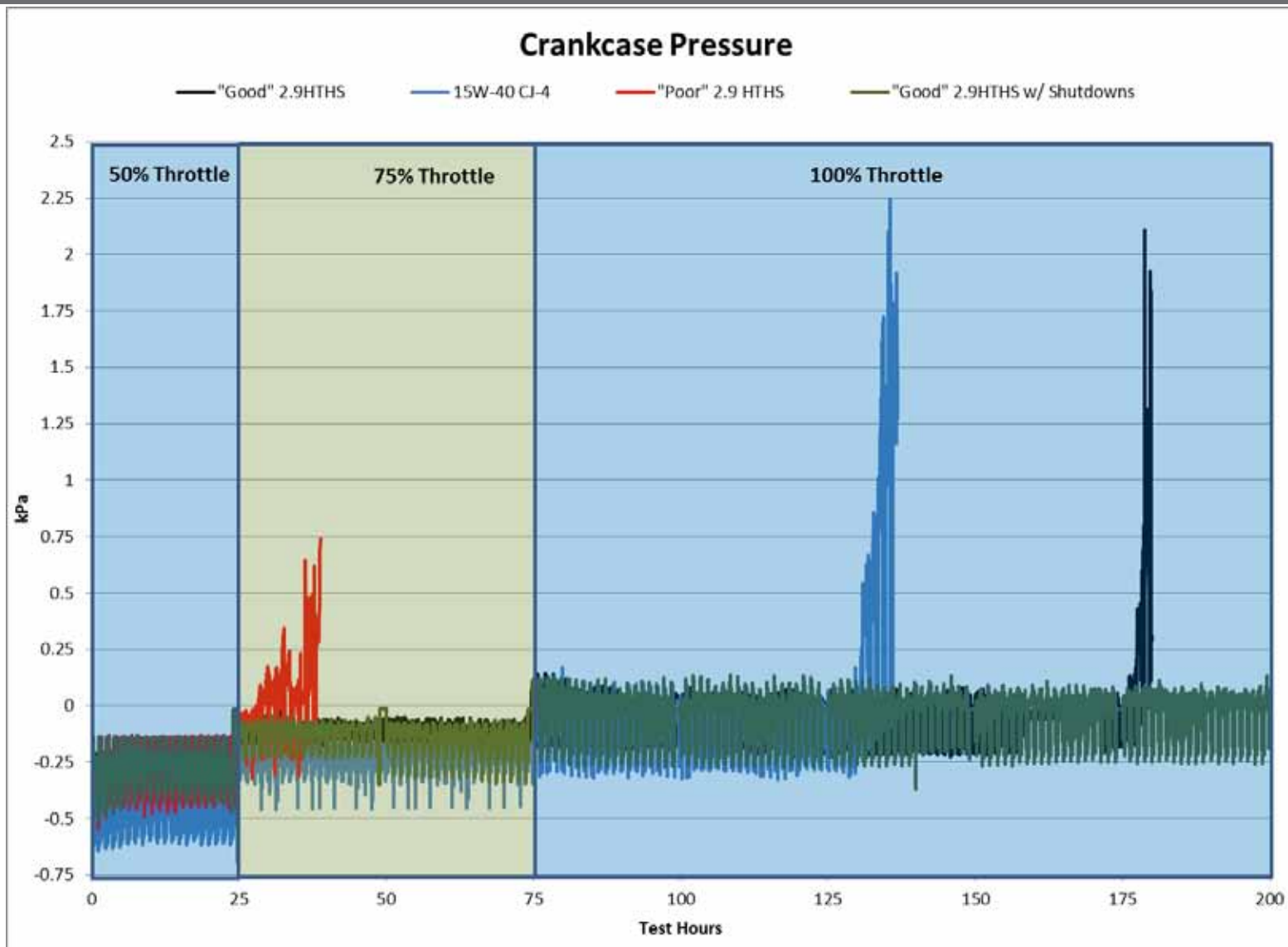
- Test ran 180 hours
 - Scuffing began at 176 hours following a shutdown
- Scuffing was seen on all cylinders
 - Cylinder 5 had only partial scuffing
- “Good” 2.9 HTHS
 - An oil based upon a fully formulated CJ-4 DI platform and believed to have good scuffing resistance at 2.9 HTHS.

Test #4 – “Good” 2.9HTHS w/ SD

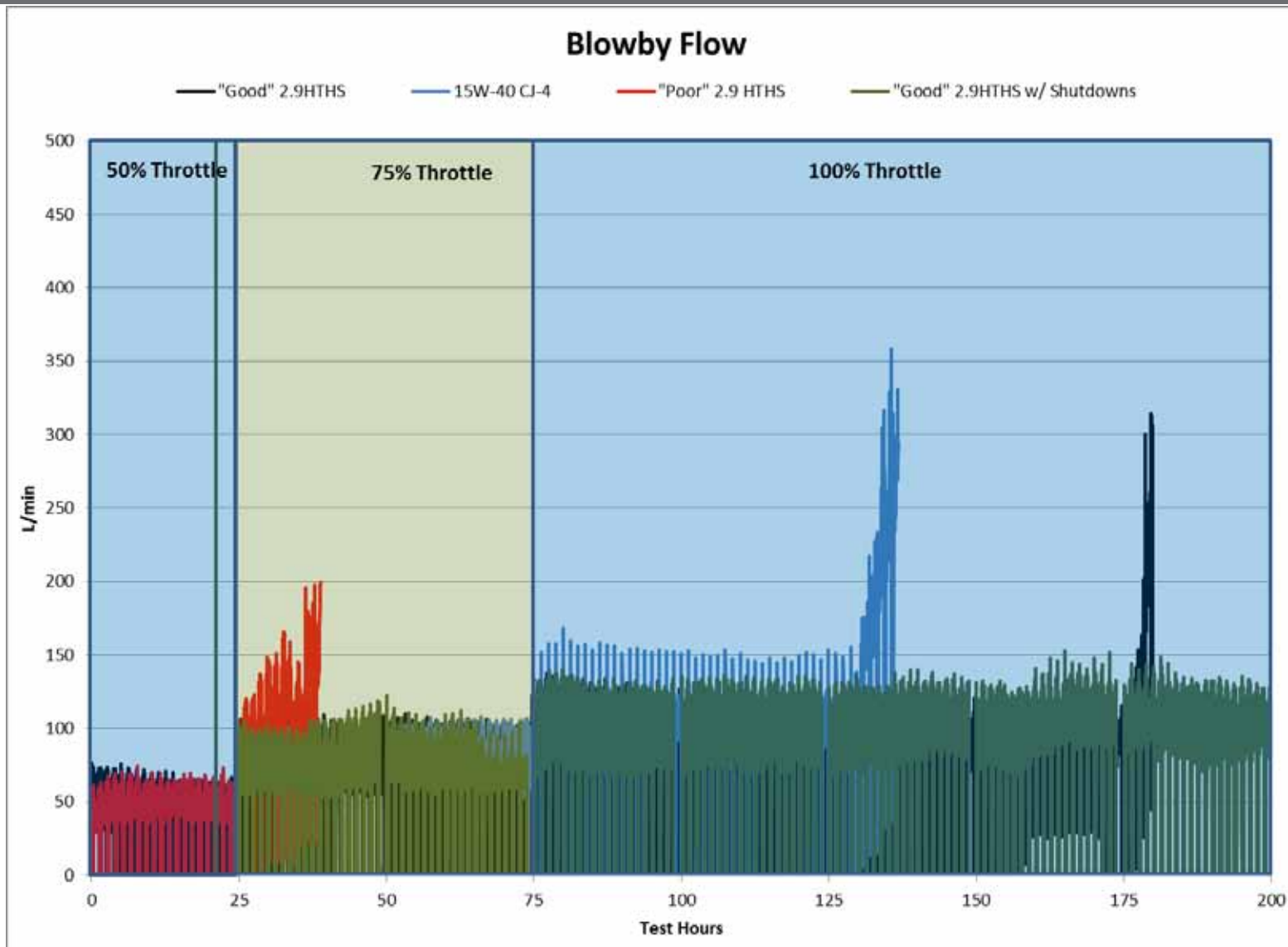


- Test #4 EOT(200HRS)
 - No scuffing
 - Ran same test cycle as first 3 tests, but with added soak every 25 hours
 - § Soaks were inserted to understand effect of shutdowns and help in test repeatability
 - Ran “Good” 2.9HTHS formulation

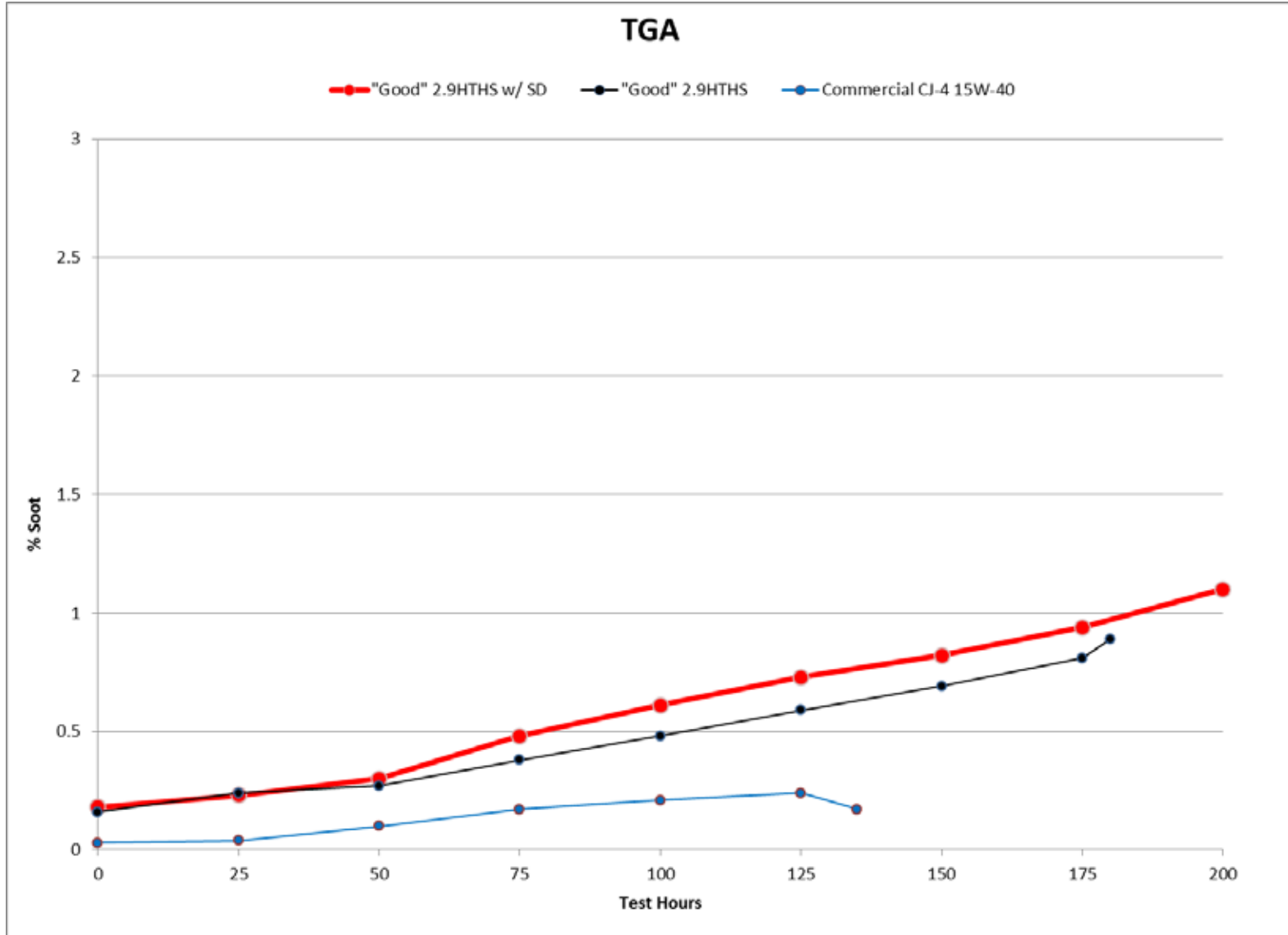
Operational Data (1 of 2)



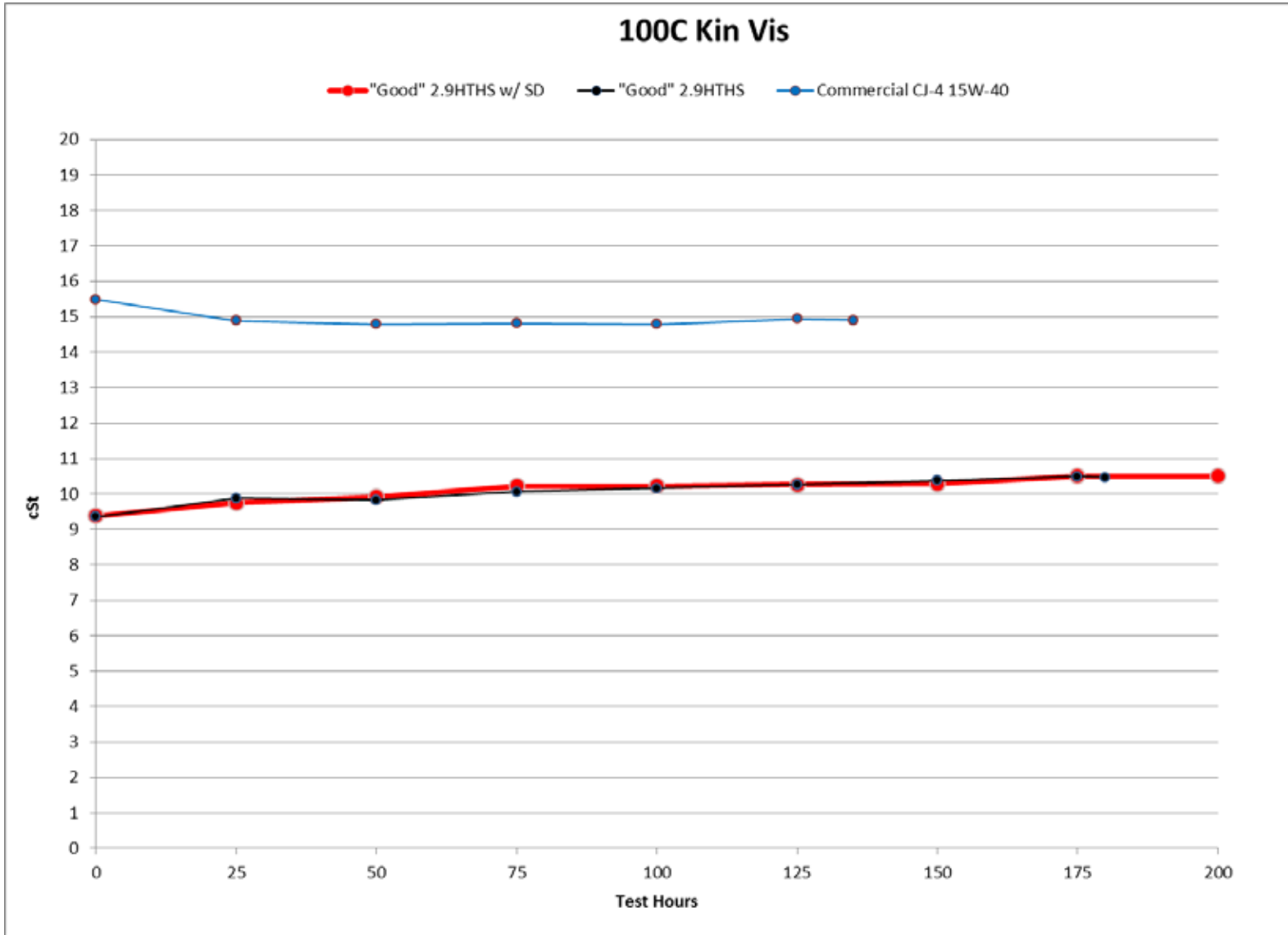
Operational Data (2 of 2)



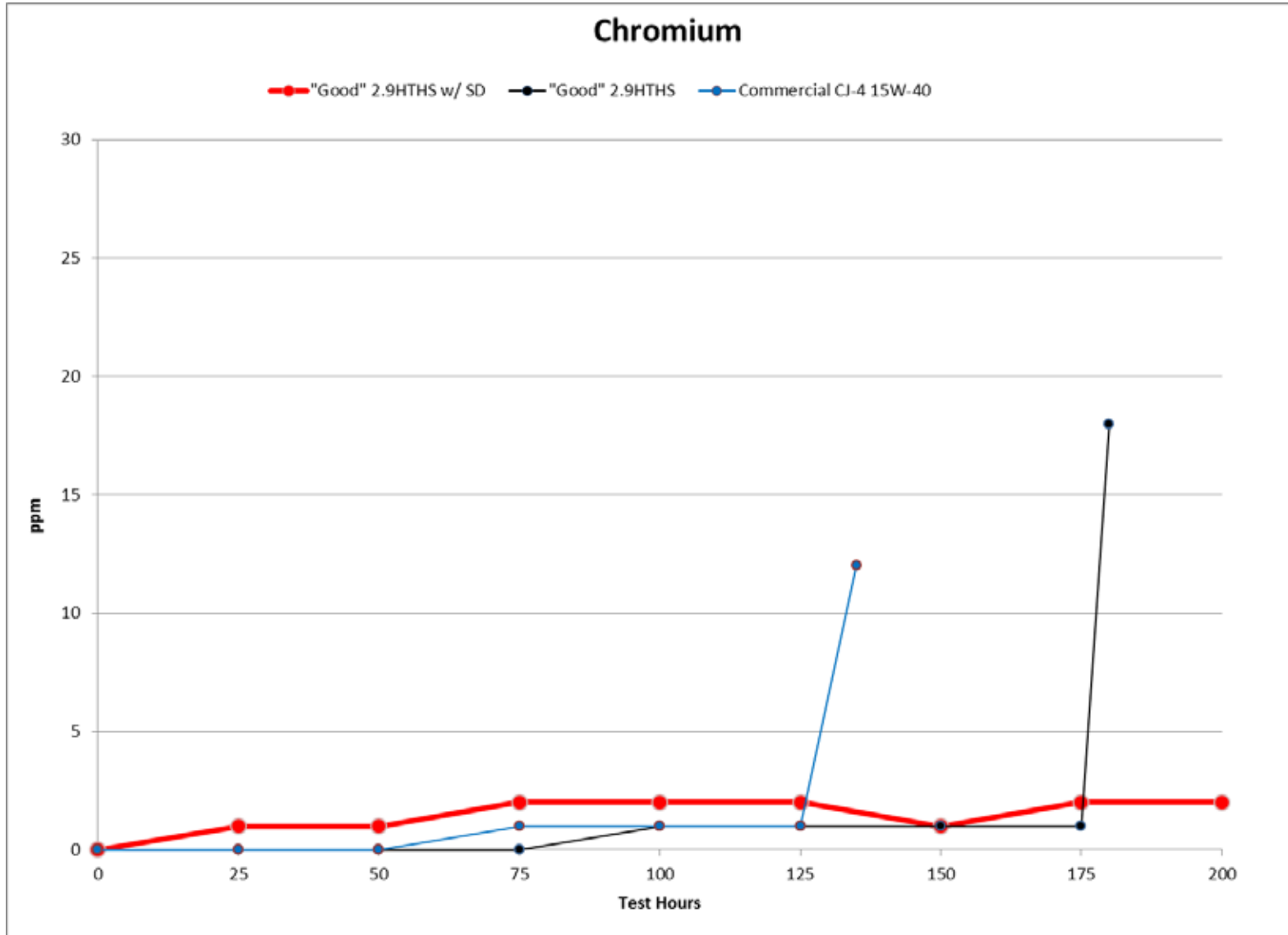
Analytical Data



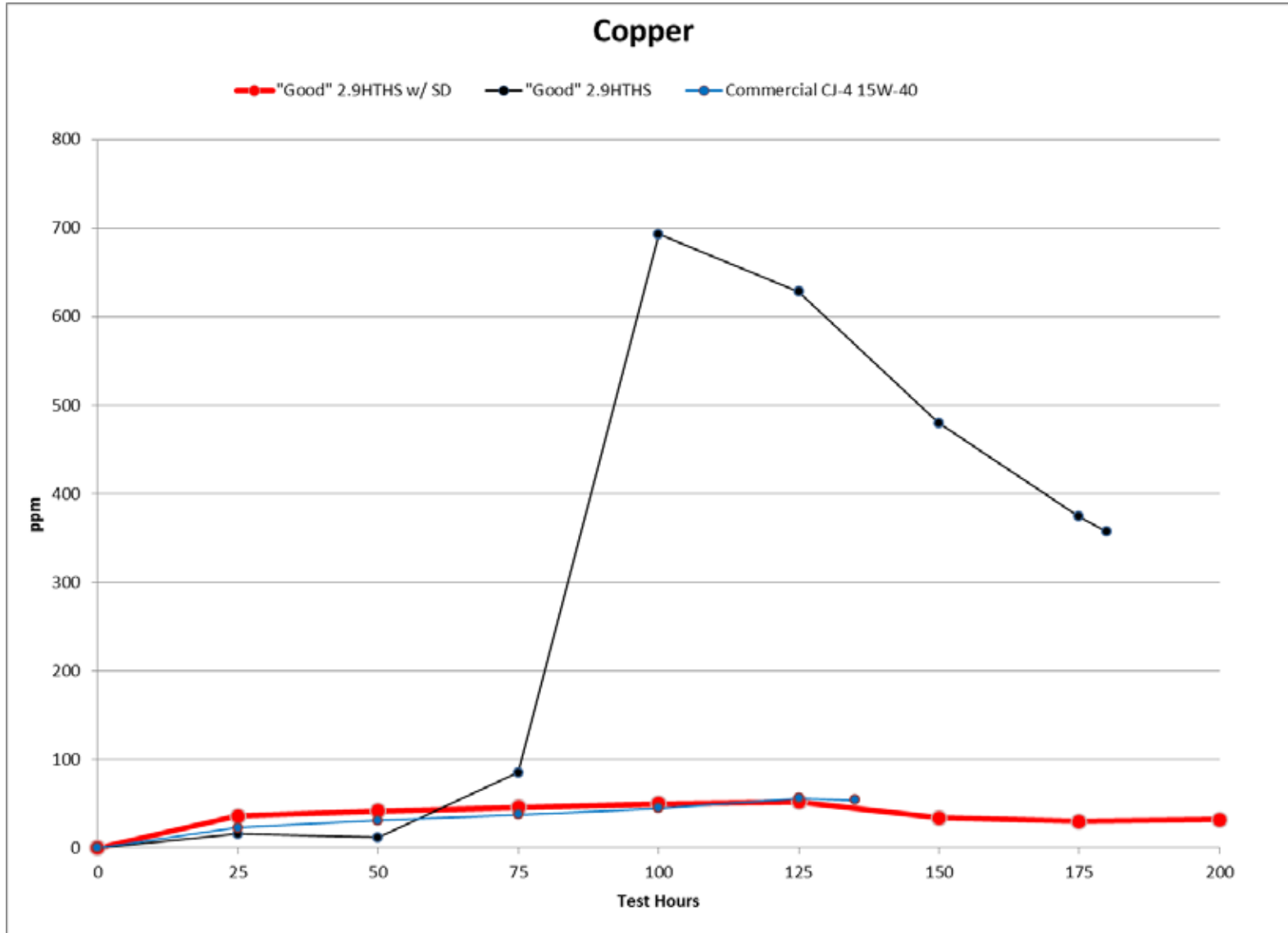
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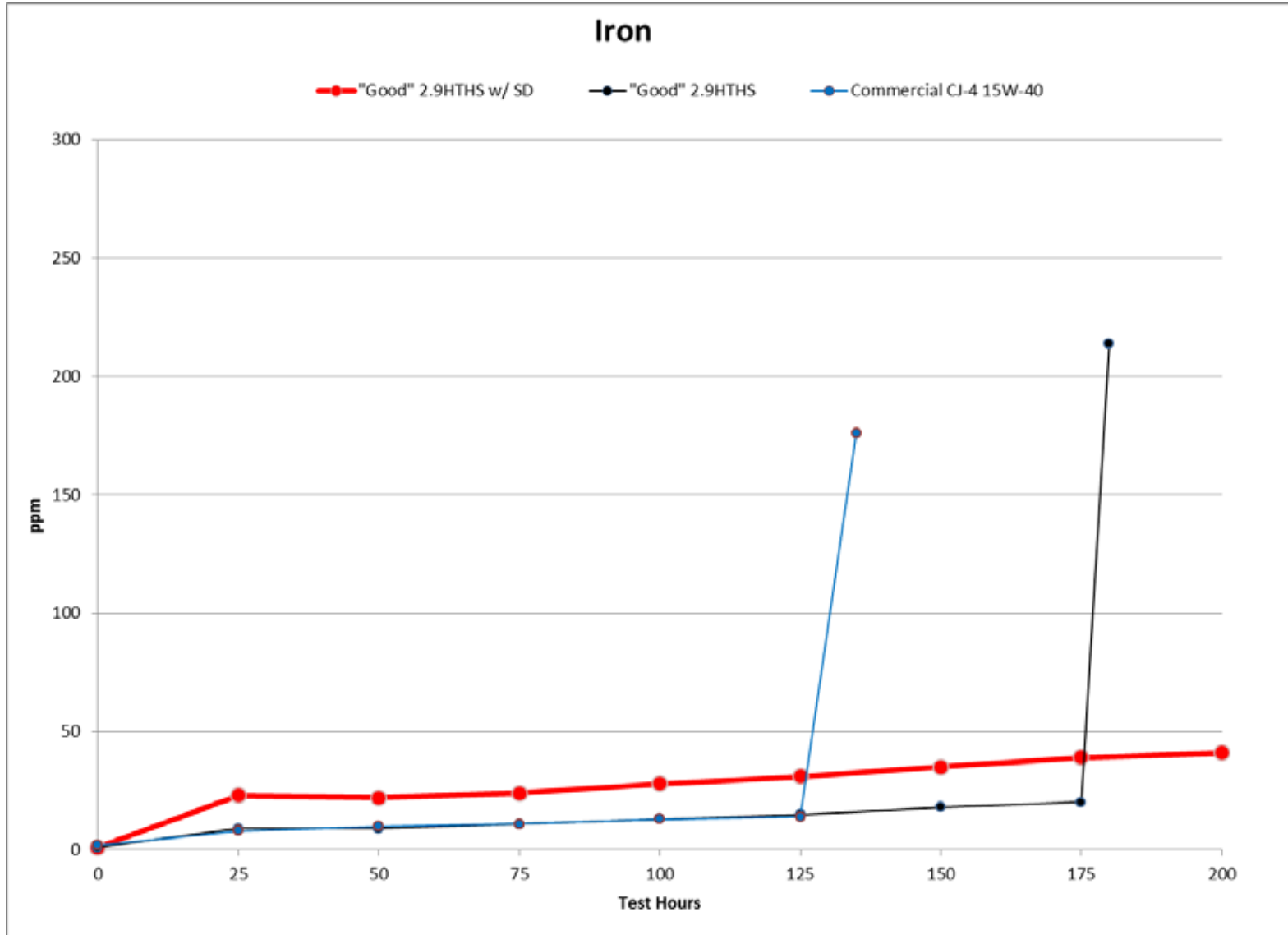
Analytical Data



Analytical Data



Analytical Data



Wear Measurements



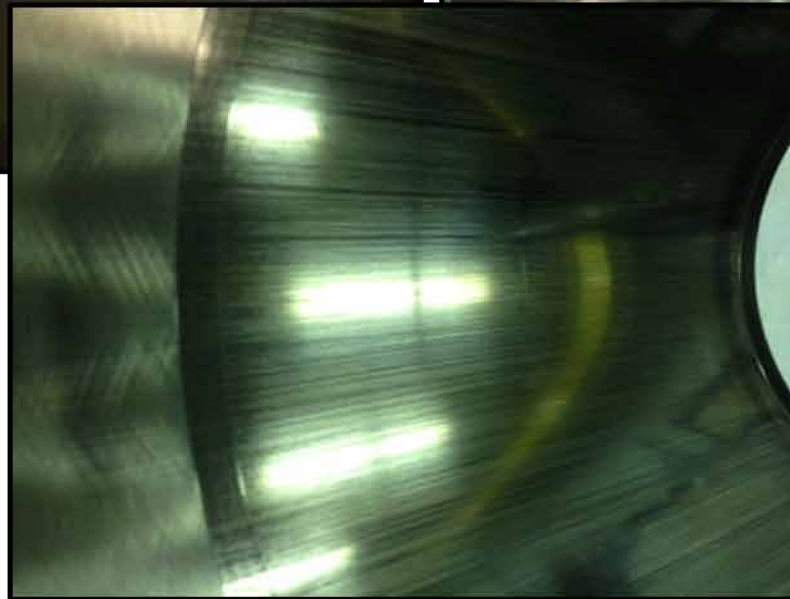
Top Ring Weightloss (mg)						
<i>Cylinder</i>	1	2	3	4	5	6
"Poor" 2.9HTHS	5.2	1.7	6.6	8544.9	1.8	6.1
15W-40 CJ-4	6796.4	6.4	7.8	4.0	4.6	7616.5
"Good" 2.9HTHS	2522.8	4952.5	2634.2	3783.1	149.8	3614.4
"Good" 2.9HTHS w/ SD	5.5	10.5	15.2	4.7	4.6	7.8

Liner Wear Step (microns)						
<i>Cylinder</i>	1	2	3	4	5	6
"Poor" 2.9HTHS	<1	<1	<1	200	<1	<1
15W-40 CJ-4	113.6	1.7	2.1	1.6	1.5	169.6
"Good" 2.9HTHS	87.5	159.2	85.4	121.1	14.2	118.0
"Good" 2.9HTHS w/ SD	2.9	2.3	2.6	2.9	3.3	3.0

Cylinder Liner Photos



SUCCESS
TOGETHER



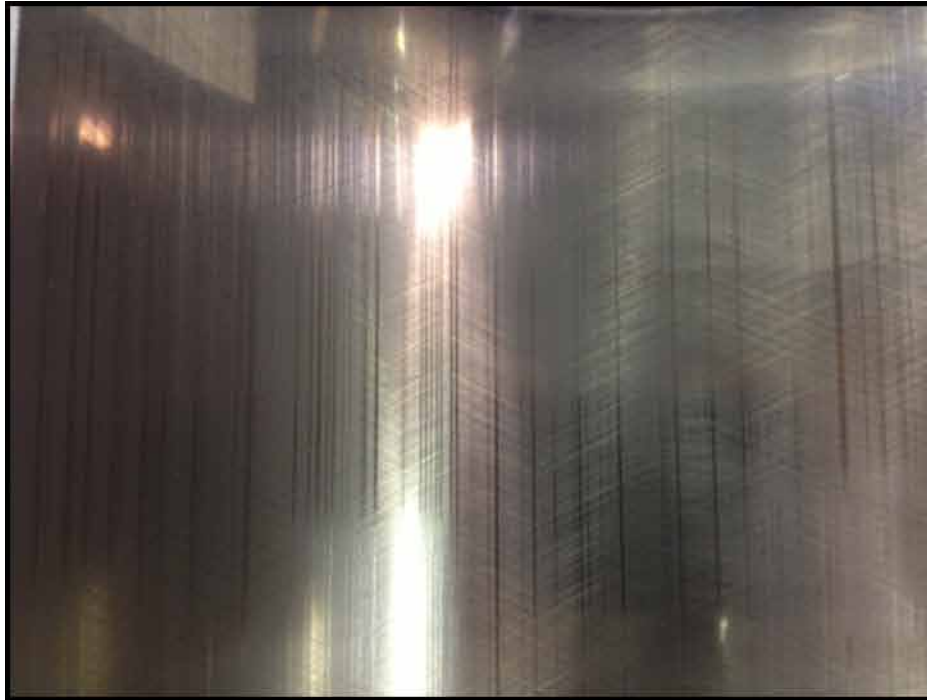
SCUFFED

Lubrizol

Cylinder Liner Photos



SUCCESS
TOGETHER

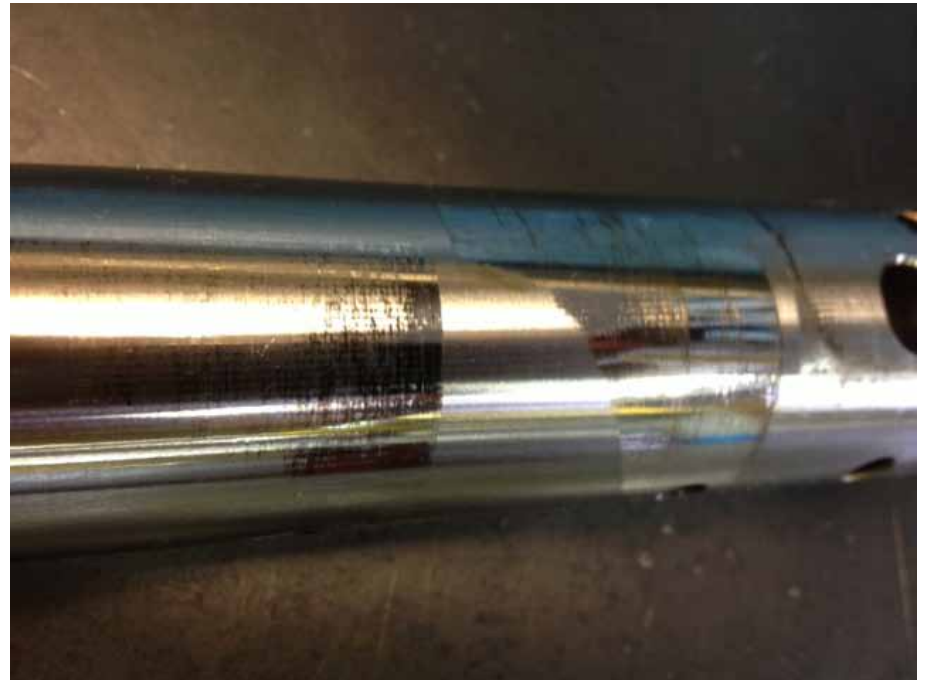


Non-SCUFFED

Rocker Shaft Photos



SUCCESS
TOGETHER



Rocker Arm Photos



SUCCESS
TOGETHER



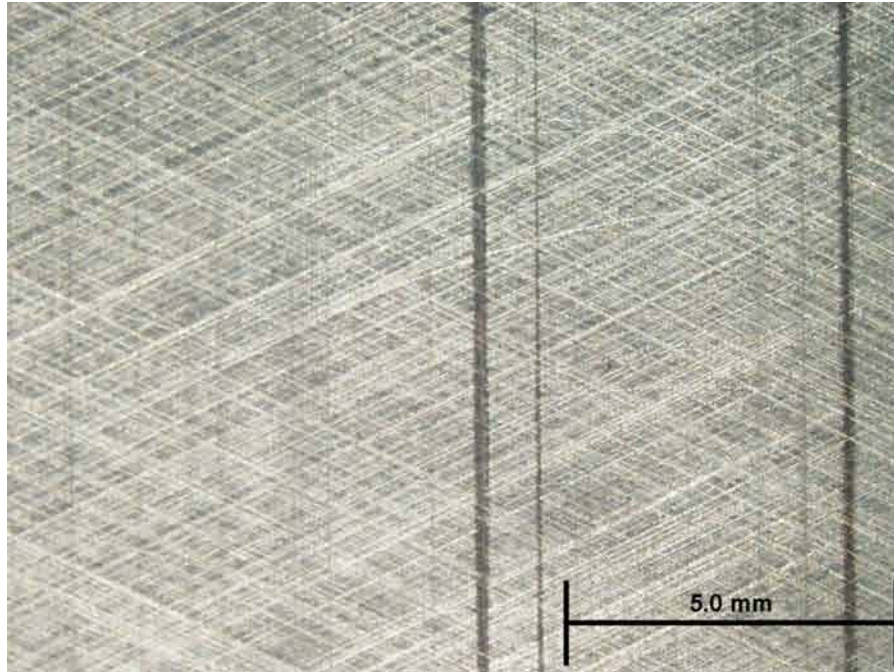


Additional Analysis

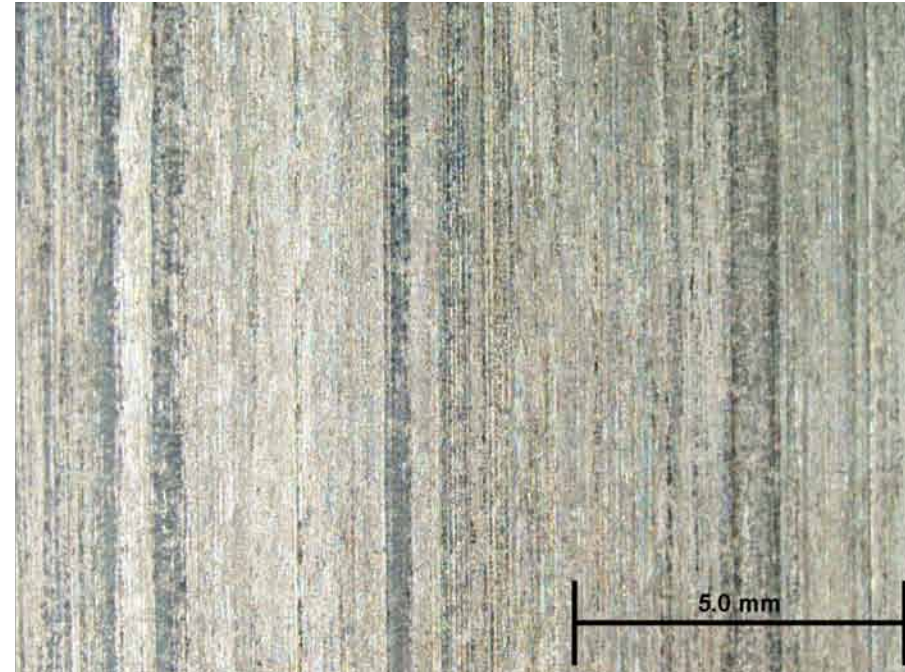
Liner Images



SUCCESS
TOGETHER



No Scuffing

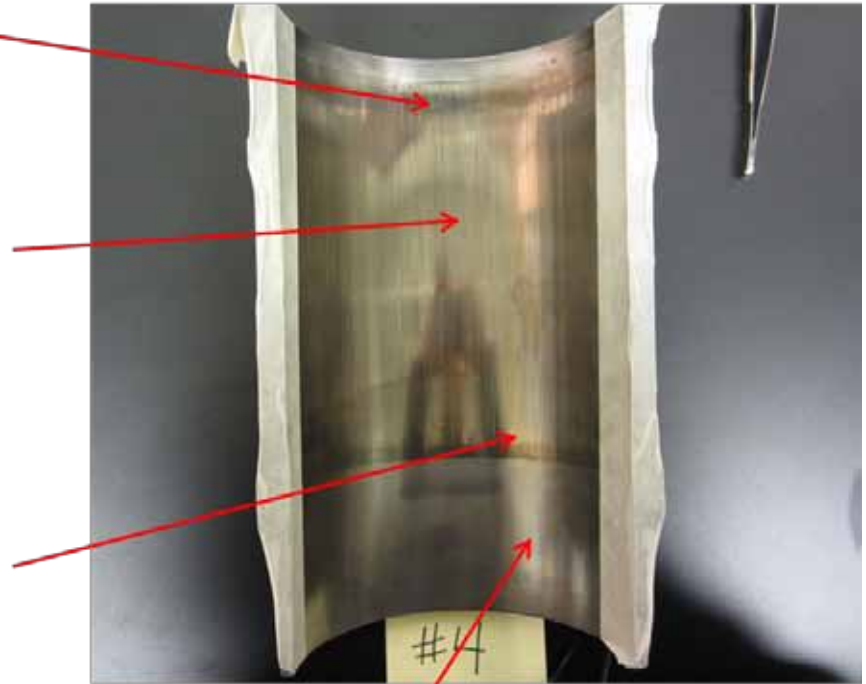
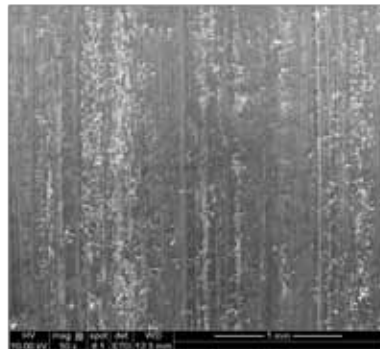
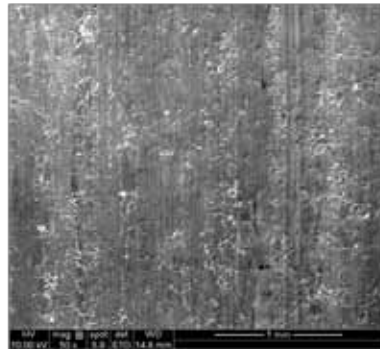
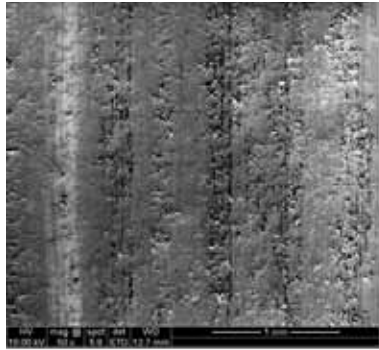


Scuffed

Liner Images



SUCCESS
TOGETHER

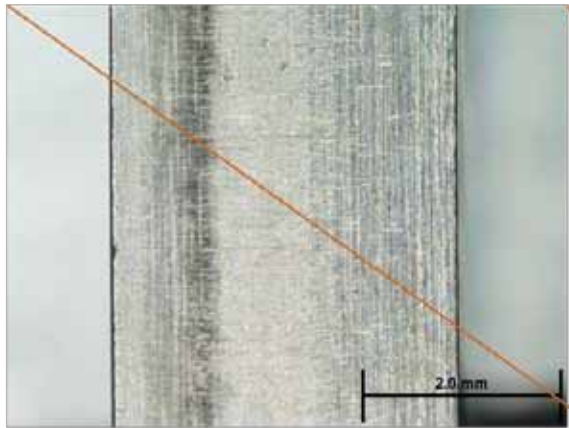


Lubrizol

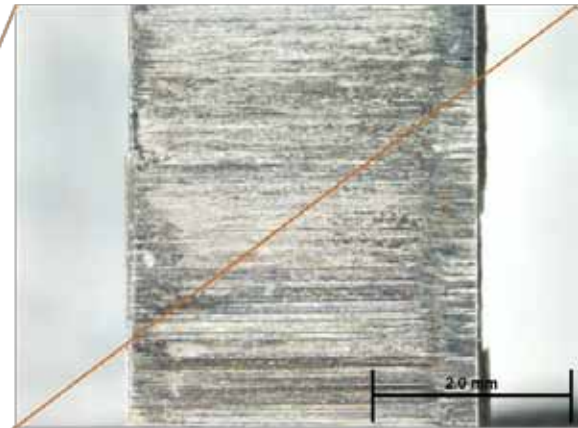
Top Ring Images



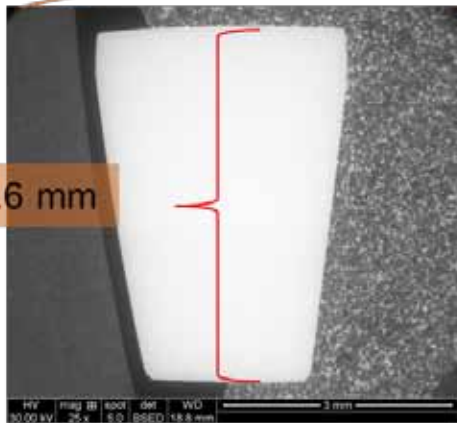
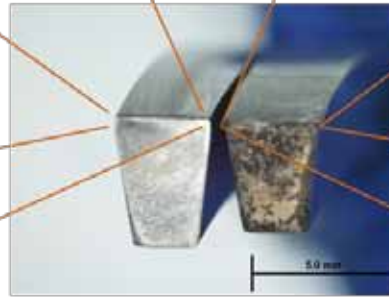
SUCCESS
TOGETHER



Top Ring Face #2 –
Optical Image

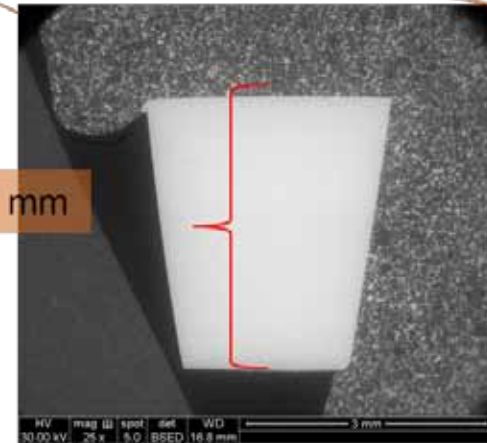


Top Ring Face #4 –
Optical Image



4.6 mm

Top Ring X section #2



3.4 mm

Lubrizol

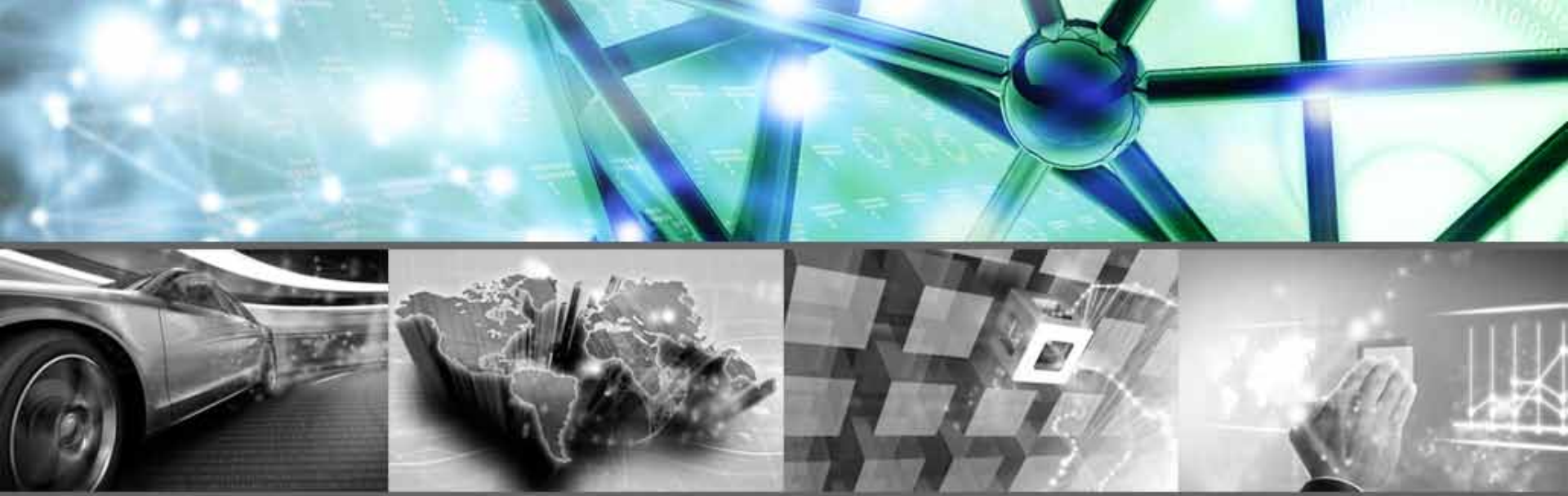


Next Steps

Next Steps



- Run “Poor” 2.9HTHS w/ Shutdowns
- Work with Intertek on stand installation
- Work with TEI on parts supply



Working together, achieving great things

When your company and ours combine energies, great things can happen. You bring ideas, challenges and opportunities. We'll bring powerful additive and market expertise, unmatched testing capabilities, integrated global supply and an independent approach to help you differentiate and succeed.