Polyalkylene Glycol (PAG) Based Lubricant for Light & Medium Duty Axles

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Ford Motor Company

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Project ID # FT023

Overview

Timeline

- Project start date – October 1, 2013
- Project end date – September 30, 2016
- Percent complete – 35%

Budget

- Total project funding - $700,000
  - DOE share: $350,000
  - Contractor share: $350,000
- Expenditure of Govt. Funds
  - FY13: $473
  - FY14: $13,321

(ANL funding not included)

Barriers

- Barriers addressed
  - Improved fuel economy
  - Use of non-petroleum based lubricants (energy independence)
  - No-harm on emissions

Partners

- Collaborations
  - ✓ Dow Chemical (not accepting DOE fund)
  - ✓ Argonne National Laboratory (ANL)
- Project lead
  - ✓ Ford Motor Company

Relevance

- **Project Objective**
  - Develop novel lubricant formulations that are expected to improve the fuel efficiency of light, medium, heavy-duty, and military vehicles by at least 2% over SAE 75W-140 axle lubricants without adverse impacts on vehicle performance or durability.
- **Objectives for this presentation**
  - Polyalkylene glycol and additive selection
  - Friction and wear data on laboratory bench tests
  - Ring and pinion gear wear data (L-37)
  - Power Transfer Unit efficiency data
- **Relevance to Vehicle Technology Office Objectives**
  - Reduce petroleum consumption by improving fuel economy
  - Reduce energy dependence by using non-petroleum based lubricants
- **Impact**
  - Reduce fuel consumption (Save 0.13 billion gallons of petroleum fuel per year[1,2])
  - New lubricant technology has no negative impact on durability and emissions

1 http://www.nada.org/NR/rdonlyres/C1C58F5A-BE0E-4E1A-9B56 1C3025B5B452/0/NADADATA2012Final.pdf
2 http://www.epa.gov/fueleconomy/fetrends/1975-2012/420s13001.pdf

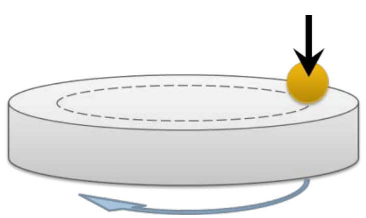
Milestones

Milestone Description	Type	Status
Budget Period 1		
Define initial PAG lubricant formulations	Technical	Completed
Define additive components	Technical	Iterative
Select lubricants showing friction and wear characteristics (on preliminary bench friction & wear tests) equal to or better than 75W-140 lubricant	Go / No-Go	Iterative
Budget Period 2		
Demonstrate formation of durable antiwear film	Technical	On Track
Demonstrate thermal performance of formulations	Technical	On Track
Select lubricants showing friction and wear characteristics equal to or better than 75W-140 lubricant	Go / No-Go	Pending
Budget Period 3		
Demonstrate 2% improvement in vehicle level fuel economy	Technical	Pending
Demonstrate durability in system (axle) level test	Technical	Pending
Axle efficiency showing improvement over 75W140 lubricant	Technical	Pending

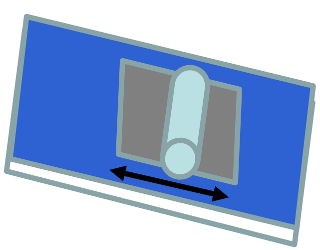
Approach / Strategy

Fundamental understanding through laboratory bench tests

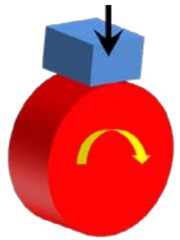
- Lubricant Formulation
  - **Selection of modified PAG oils**
    - Matching viscosity target
  - **Selection and rough optimization of additive package**
    - Laboratory oxidation tests
    - Copper corrosion tests
    - Rust prevention tests
    - Friction tests (MTM, Pin-on-disk, HFRR, Block-on-disk)



Pin-on-disk
(Pure Sliding)



HFRR
(Pure Sliding)



Block-on-Ring
(Pure Sliding)

- Wear tests (Four Ball, Falex EP, Pin-on-disk, HFRR)
- Fatigue and micro-pitting tests

Approach / Strategy

System level evaluations

- Thermal and oxidative stability (L-60) tests
- Moisture corrosion resistance (L-33-1) tests
- Load carrying properties under low speed and high torque conditions(L-37)
- Load carrying properties under high speed and shock loading conditions (L-42)

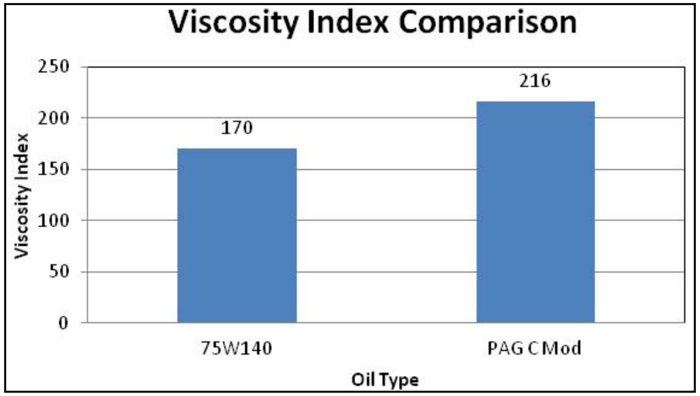
Approach / Strategy

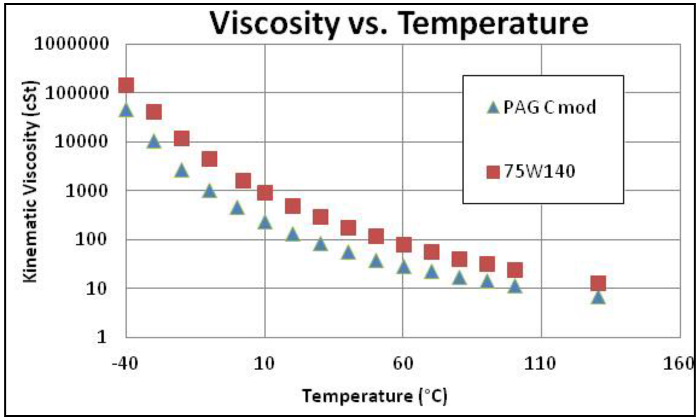
System level (more complex) and vehicle level evaluations

- **Hypoid gear wear test (Ford proprietary)**
- **Axle efficiency test (Ford proprietary)**
- **Chassis roll fuel economy and emissions tests**

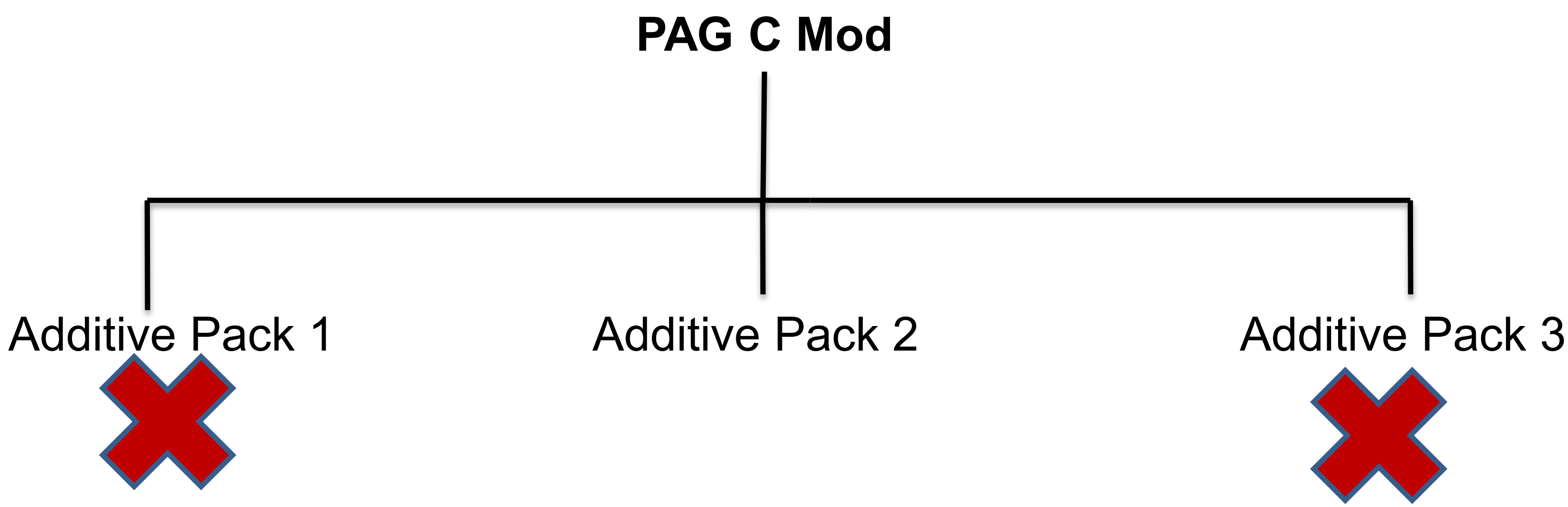
Technical Accomplishments and Progress

- **Lubricant Selection**
  - PAG C Mod was selected from seven PAG oils based on rheological properties
- **Additive package selection**
  - Three packages were initially selected based on experience
- **Chemical properties evaluation**
  - Thermal and Oxidative Stability of Lubricating Oils test (Modified ASTM D 5704)
  - Copper Corrosion test (ASTM D130)
  - Rust Prevention test (ASTM D665A)
  - Material (Seal) Compatibility test
- **Friction and wear properties evaluation**
  - Falex EP test (ASTM D 3233 test method A)
  - 4 Ball wear test
  - Mini-Traction Machine (sliding/rolling friction)
  - Pin-on-disk test (sliding friction)
  - High Frequency Reciprocating Test (sliding friction)
  - Block-on-ring test (load to failure)

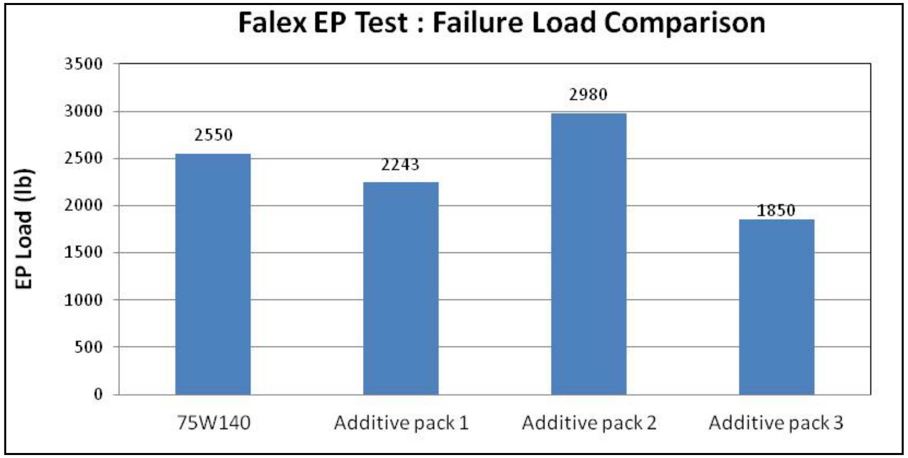




Technical Accomplishments and Progress

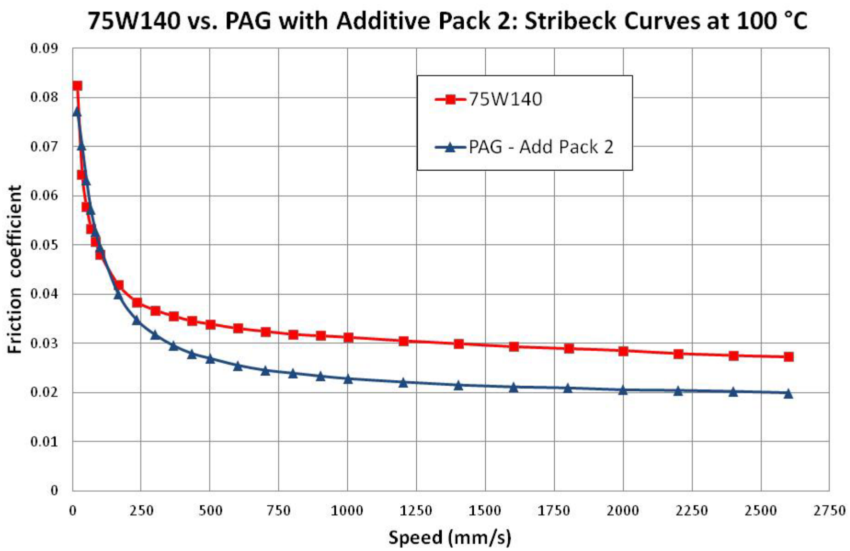


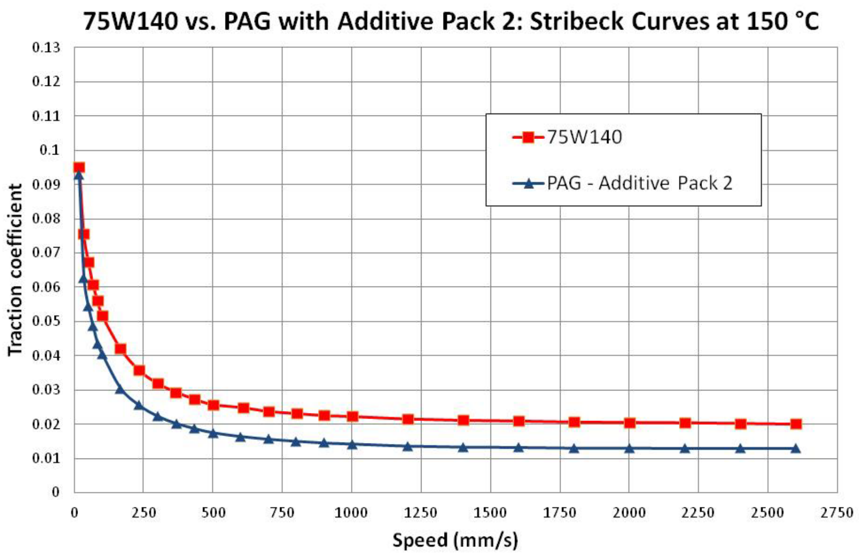
- Additive package 1 & 3 chemistry showed lower failure loads (Falex EP test) compared to 75W140 formulation and thus eliminated
- Additive package 2 showed improved performances over 75W-140 in all tests with little debit on copper corrosion test
- Focused on optimizing additive package 2



Technical Accomplishments and Progress

Traction Coefficient Comparison: Additive Pack 2





PAG oil showed lower traction coefficients than 75W140

Technical Accomplishments and Progress

Formulation	TOST	4 Ball wear (mm)	Falex EP (lb)	4 Ball EP (kg)	Ball on disc (ball wear) (mm)	Ball on disc (disc wear) (mm)	Rust Prevention	Copper Corrosion
75W140 Benchmark	20% viscosity increase ▲TAN = 1.5	0.42	2807	420			Pass	2A
201302484-17-2 201302484-58-1 (Option 2_1)	4.7% viscosity increase ▲TAN = 0.4	0.58	3609	400	0.48	0.47	Pass	1B
201302484-38-1 (Option 2_1_a)	13% viscosity increase ▲TAN = 0.5	0.5		**340**				1B
201302484-39-1 (Option 2_1_b)	6% viscosity increase ▲TAN = 0.2	0.58		**340**				1B
201102796-70-9 (Option 2_1_c)	5.8% viscosity increase ▲TAN = 0.7	0.47	4500		0.39	0.36	Pass	1B
201302484-67-6 (Option 2_1_d)	8.8% viscosity increase ▲TAN = 0.66, Some Deposits		3263		0.34	0.31	**Fail**	1B
201102796-71-5 (Option 2_1_e)					0.33	0.29	Pass	1B
201302484-18-2 (Option 2_2)	9.5% viscosity increase ▲TAN = 0, Deposits	0.53	3318	480			**Marginal**	1A
201302484-12-1 (Option 2_3)	**13.4% viscosity increase ▲TAN = 1**	0.55	NA	380	0.39	0.34	Pass	1B

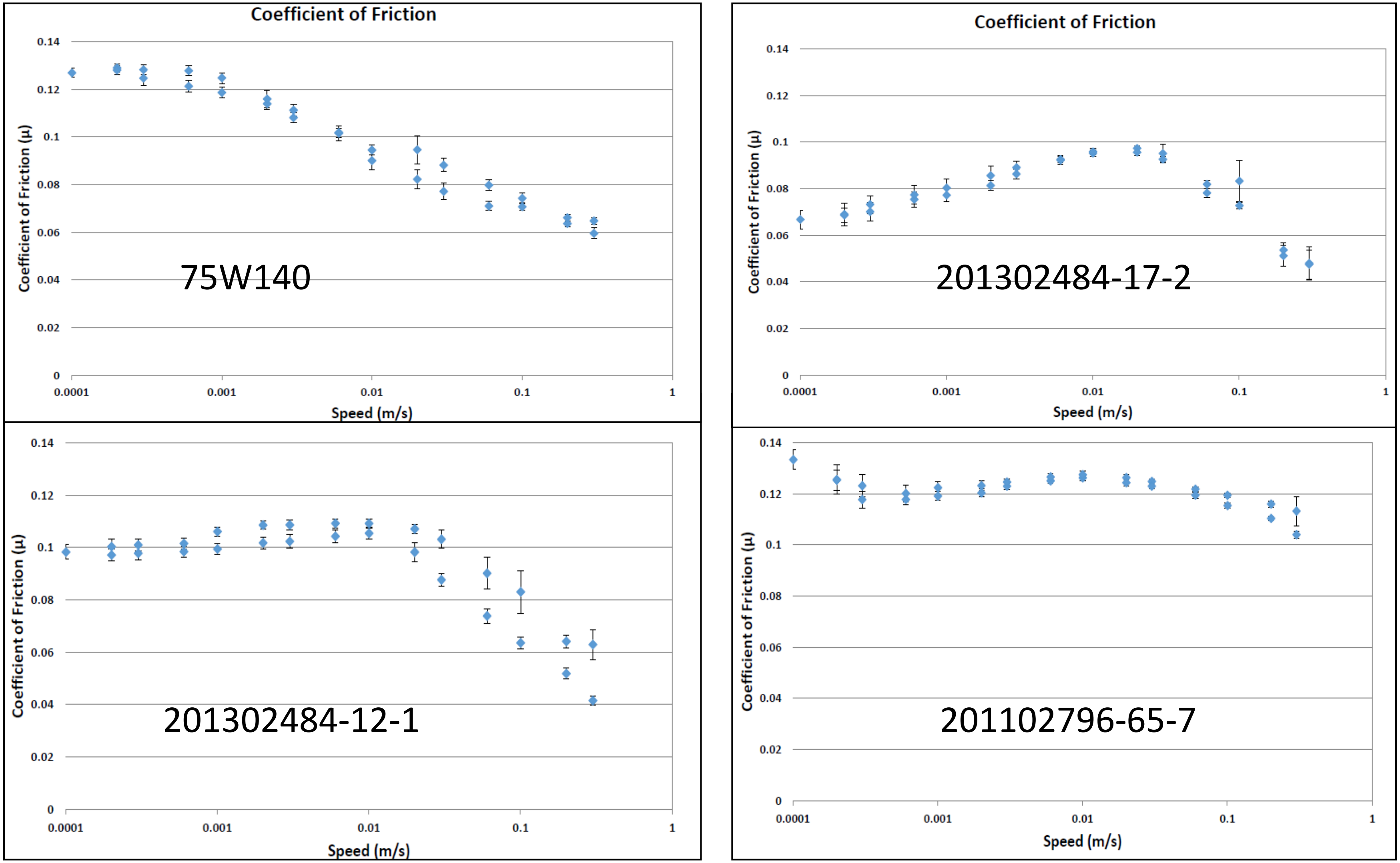
Option 2_# : Products use additive pack # 2

Option 2_1_a-e: Products use the core 2_1 additive pack with minor component tweaks

: Current state of formulation

Technical Accomplishments and Progress

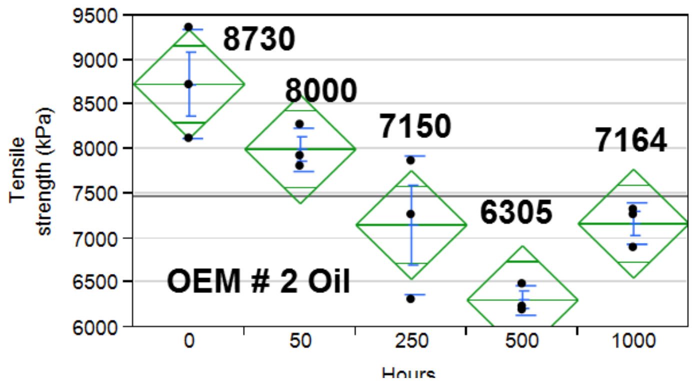
Pin-on-Disk test at 100 deg C

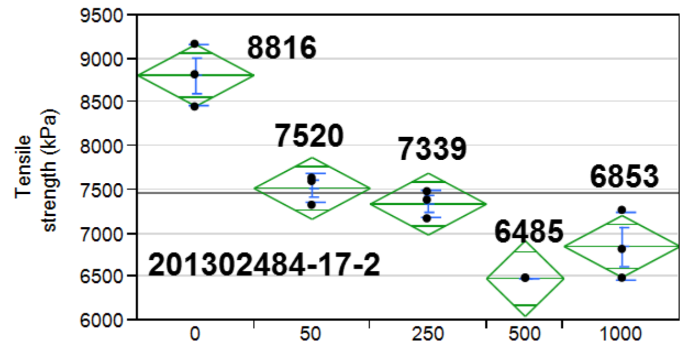


201302484-17-2 show lower coefficient of friction than 75W140

Technical Accomplishments and Progress

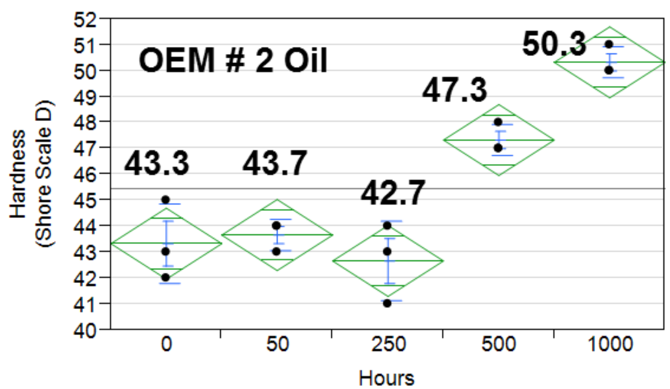
Seal Material Compatibility (1000 hrs at 150C)

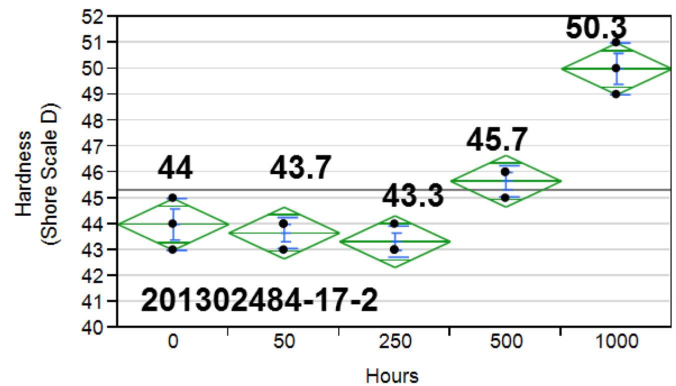




FKM V41 material

. Similar performance





ACM material

. Not acceptable

Technical Accomplishments and Progress

Load Carrying Capability under Low Speed High Load Conditions (L-37)

Oil Code: 201302484-17-2

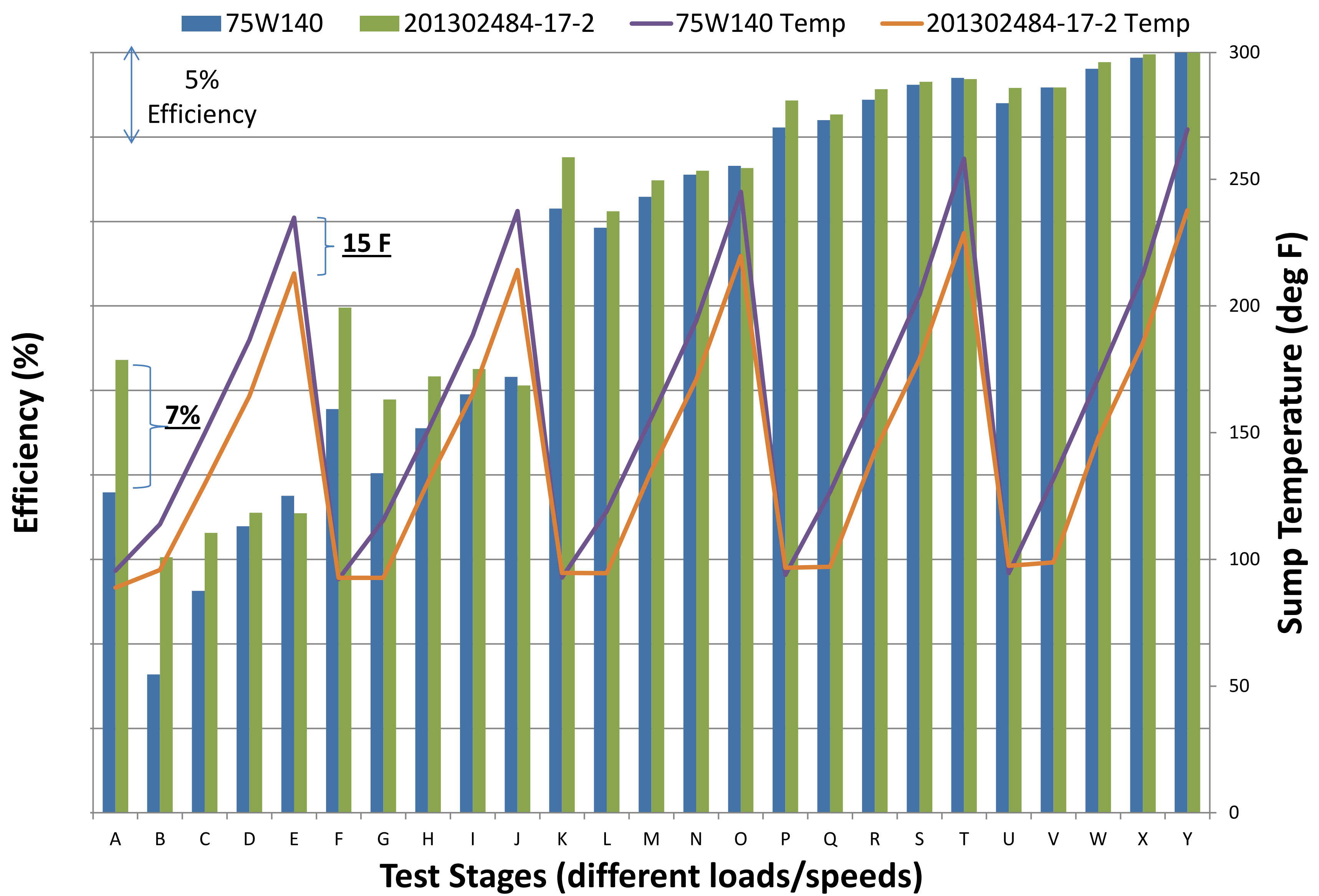
	Acceptance Criteria	Original Ring Rating	Original Pinion Rating
Wear	8	**7**	**6**
Rippling	8	**8**	**5**
Ridging	8	**8**	**8**
Pitting / Spalling	8	**9.9**	**9.7**
Scoring	8	**10**	**10**

Fluids	KV @100C	KV @40C
75W140	25.2 cSt	183.9 cSt
PAG 17-2	12 cSt	59 cSt

EXPERIMENTAL GEAR OIL
PINION
DRIVE SIDE

Technical Accomplishments and Progress

PTU Efficiency Testing



Collaboration and Coordination with Other Institutions

- **Dow Chemical – Collaborator (not accepting DOE fund)**
  - Responsible for
    - PAG oil formulations
    - Viscometric characterizations
    - ASTM tests (L-33-1, L-37, L-42, L-60)
- **Argonne National Laboratory – Subcontractor**
  - Responsible for
    - Laboratory bench tests for friction and wear evaluation
      - Pin-on-disk tests
      - Block-on-ring tests
      - Reciprocating roller-on-disk tests
      - Fatigue and micro-pitting tests
    - Understand friction reduction mechanism through analysis of wear surfaces using x-ray photoelectron spectroscopy, Raman spectroscopy etc.

Remaining Challenges and Barriers

- Improve rippling performance in L-37 test (wear protection capability)
- Demonstrate load-carrying capability under high speed and shock loading conditions (L-42)
- Demonstrate thermal and oxidative stability (L-60)
- Demonstrate vehicle fuel economy benefits
- Lack of participation of any additive company

Proposed Future Work

Remaining FY 15

- Assess fatigue and micro-pitting performance
- Understand rippling (L-37 test) characteristics and re-formulate
  - Ensuring no degradation in other performance attributes
- Explore other PAG base oils
- Assess performances in
  - L-60 test (Thermal and oxidative stability
  - L-33-1 test (Moisture corrosion resistance)
- Understanding friction reduction mechanism
  - Through analysis of wear surfaces

Proposed Future Work

FY 16

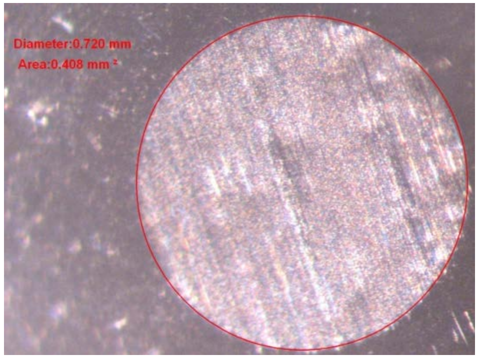
- **System and Vehicle Evaluation**
  - System Evaluation
    - Axle efficiency tests
    - Load carrying capability (L-37) tests
    - Load carrying capability (L-42) tests
    - Hypoid gear wear tests
  - Vehicle level tests
    - Vehicle Fuel Economy Tests

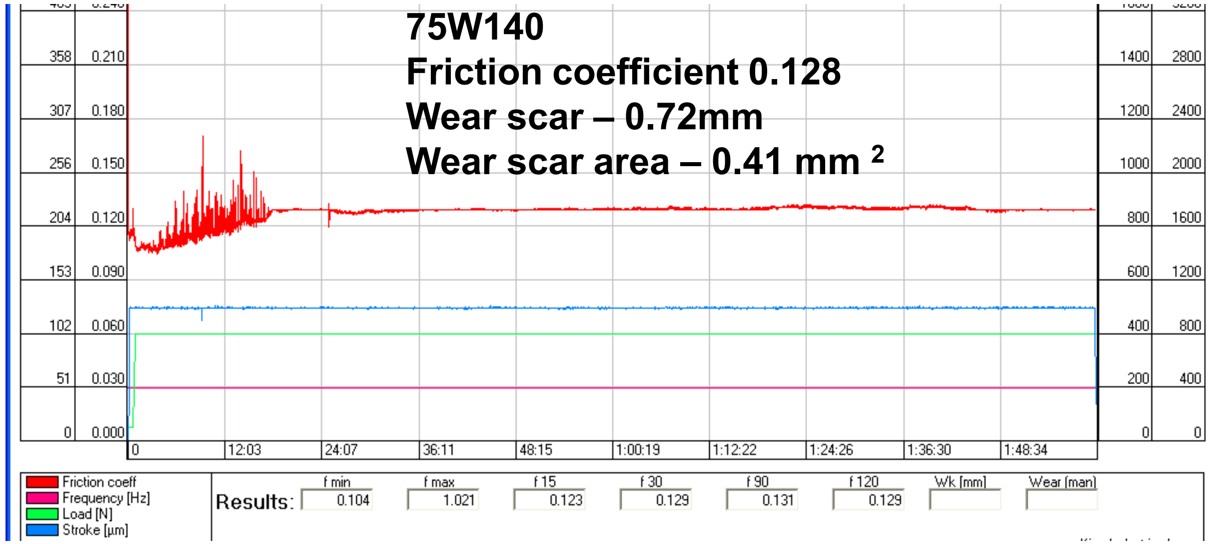
Summary Slide

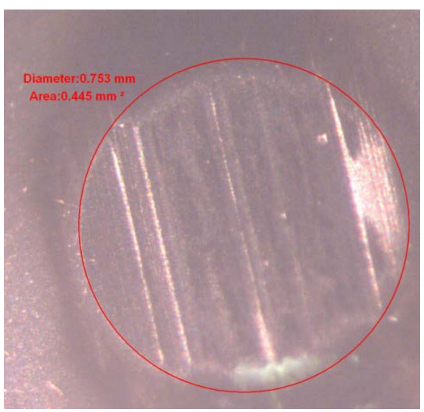
- Identified various test methods and test conditions for evaluating PAG formulations against SAE 75W-140
- Identified a PAG base oil and selected one additive package delivering bench test performances equal to or better than SAE 75W-140
- Preliminary results showed encouraging L-37 test performance with minor issue with rippling
- Power Transfer Unit results showed up to 7% efficiency improvement and 15F lower temperature in low torque stages

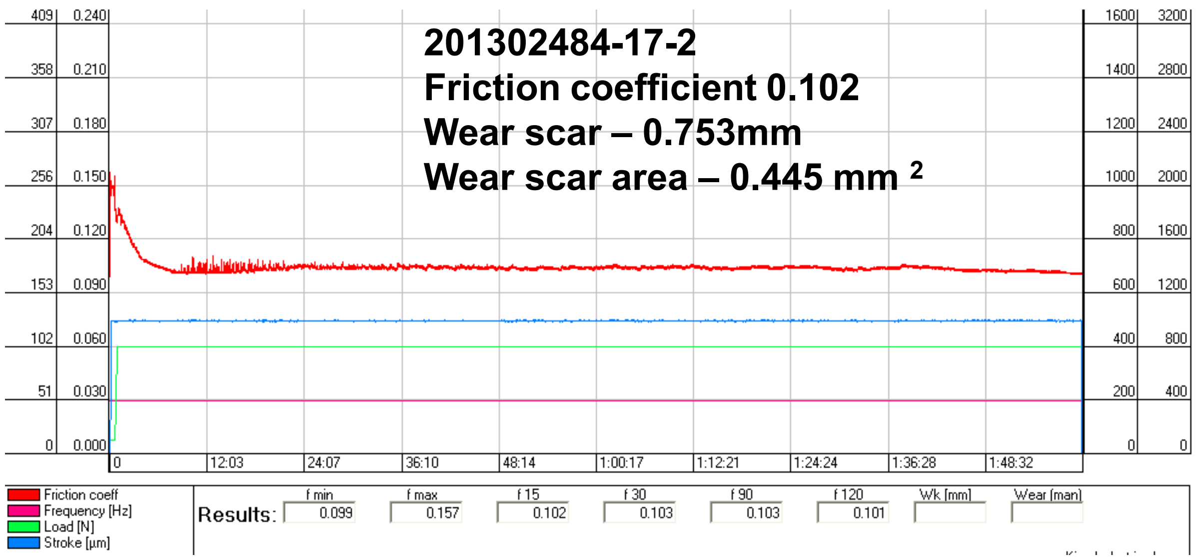
Technical Back-Up Slides

AW / EP Performance (SRV)

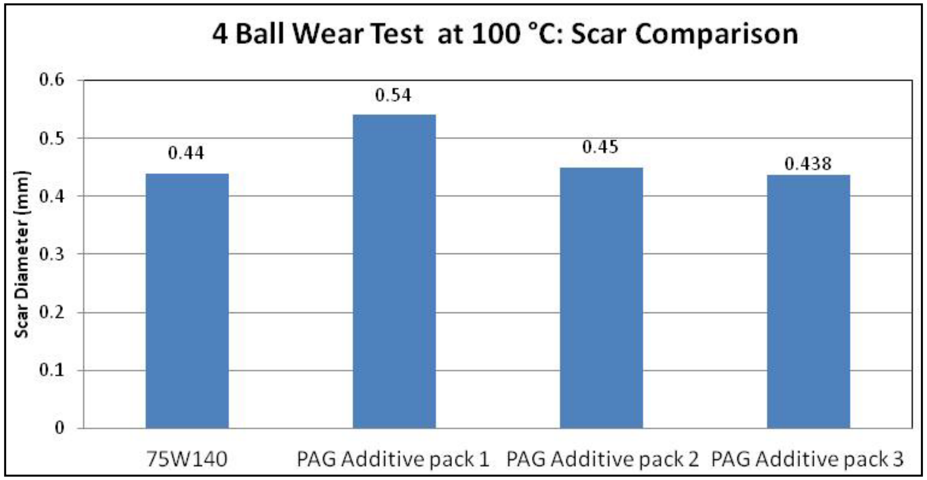


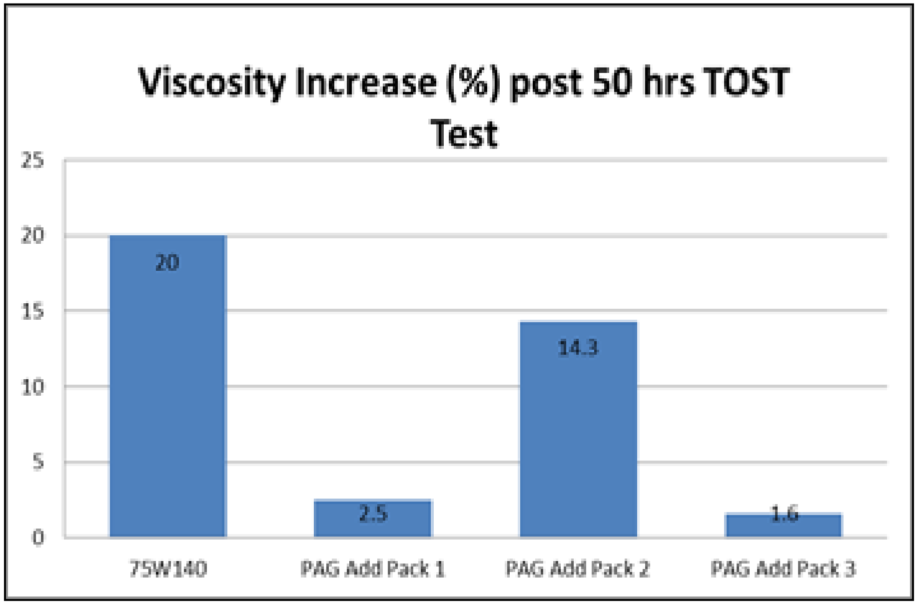






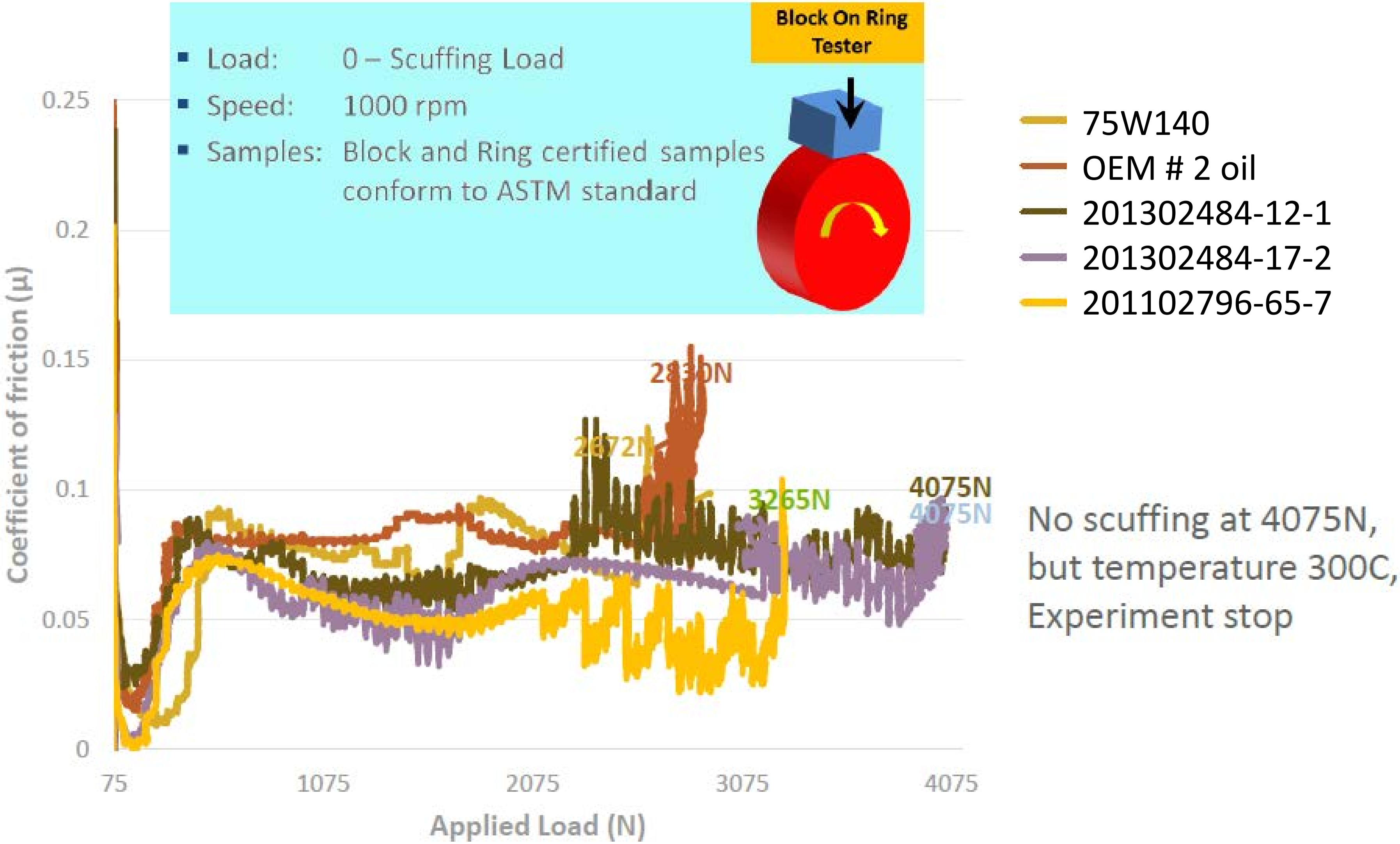
Wear & Oxidation Performance Data





- ❖ 3 different additive packages with PAG oil show comparable wear to the benchmark 75W140 formulation
- ❖ All add packs show improved oxidation resistance

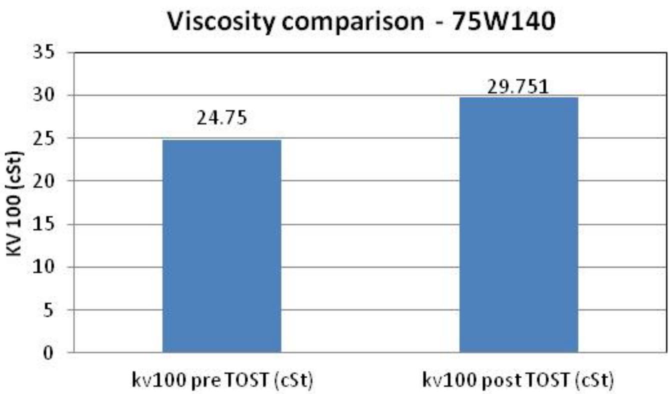
Technical Accomplishments and Progress



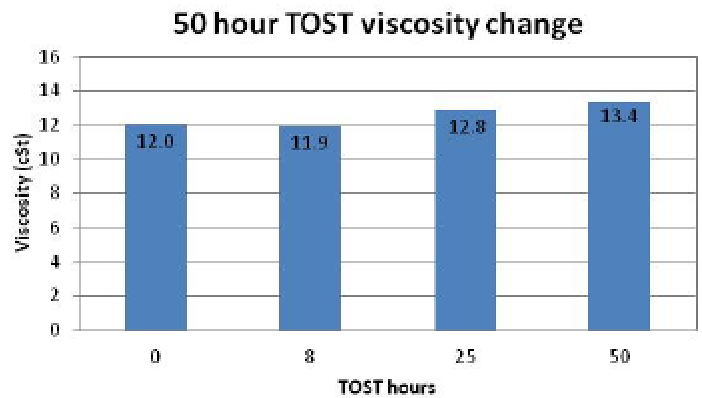
201302484-17-2 showed much improved load carrying capability than 75W140

Thermo-oxidative Stability Performance

75W140 at 150C / 50 hours



201302484-17-2 at 150C / 50 hours



50 hr post TOST

Post test RBF

Rust Prevention (ASTM D665A)

Pass

75W140

Pass

Additive Package 1

Pass

Additive Package 3

Pass

Additive Package 2
201302484-17-2

- **All the three additive packages meet the rust prevention test requirement as outlined in ASTM test method 665A**