

# Cummins ISB *Mostly Official* Matrix Analysis

October 26, 2005

# Analysis Summary

- 17 Valid Tests Analyzed
  - 15 Matrix Tests, 2 Reference Tests
  - Tappet Wear, Camshaft Wear, Crosshead Wear
- E178 (95% CI) Used on Wear Results
  - Wear Profile Offset Not Necessary
  - All Results and Analysis Outlier Screened
- Wear Relationship with Soot Possible
  - Tappet Wear and Crosshead Wear
  - Correlations with Stand and Stage B Average Torque

# Analysis Summary

- Possible Lab/Stand Effects
- No Transformations
  - Higher Wear Oils Would Likely Require
- Oil Discrimination
  - Tappet Weight Loss
  - Possible for Camshaft Wear (Model Dependent)
- All 3 Wear Parameters Meet ACC Precision
  - Note that Tappet Wear Between Stands and Labs Does Not

# Concerns

- Model Dependent Conclusions
  - Some Confounding (Stand, Stage B Average Torque, and Soot)
- Correcting Camshaft Wear for Stage B Average Torque
  - Correcting Test Results for an Operational Parameter is not an Ideal Situation.
- Reference Frequency Given Engine, Stand and Lab Differences
  - Very Large Stand Effects for Tappet Wear

# Precision Summary

	Repeatability s (Within Stand)	Reproducibility s (Between Stand)	Reproducibility s (Between Lab)
Tappet Wear (mg) Soot Adj	8.1645 Ep=1.84	16.8574 Ep=0.89	16.9092 Ep=0.89
Camshaft Wear (um)	4.7021 Ep=3.19	7.1512 Ep=2.10	7.1512 Ep=2.10
XHead Wear (mg) Soot Adj	0.3817 Ep=1.96	0.3817 Ep=1.96	0.5221 Ep=1.44
Torque Adjstd Cam Wear (um)	5.0833 Ep=2.95	5.0833 Ep=2.95	6.3063 Ep=2.38

# Target Summary

	Oil 830-2	PC10B	PC10E
Tappet Wear (mg) Soot Adj	LS Mean = 88.23 Mean = 85.8167 S = 16.1416	LS Mean = 93.47 Mean = 88.6833 S = 15.8176	LS Mean = 67.54 Mean = 57.86 S = 9.4796
Camshaft Wear (um)	LS Mean = 40.20 Mean = 40.2667 S = 9.2058	LS Mean = 44.85 Mean = 41.9833 S = 5.6722	LS Mean = 36.86 Mean = 34.14 S = 5.0093
XHead Wear (mg) Soot Adj	LS Mean = 2.072 Mean = 2.0833 S = 0.5345	LS Mean = 2.057 Mean = 2.0667 S = 0.4367	LS Mean = 1.940 Mean = 2.0000 S = 0.4743
Torque Adjstd Cam Wear (um)	LS Mean = 40.86 Mean = 40.86 S = 6.8895	LS Mean = 42.29 Mean = 42.2984 S = 4.7694	LS Mean = 33.94 Mean = 33.0695 S = 6.0193

# Correlation Summary

Between Oil and Within Oil Correlations

Between Oil	OSACSW	OSATWL	OSACWL
OSACSW	1.00	0.79	0.56
OSATWL	0.79	1.00	0.54
OSACWL	0.56	0.54	1.00

Within Oil	OSACSW	OSATWL	OSACWL
OSACSW	1.00	0.54	0.33
OSATWL	0.54	1.00	0.20
OSACWL	0.33	0.20	1.00

# Average Tappet Weight Loss

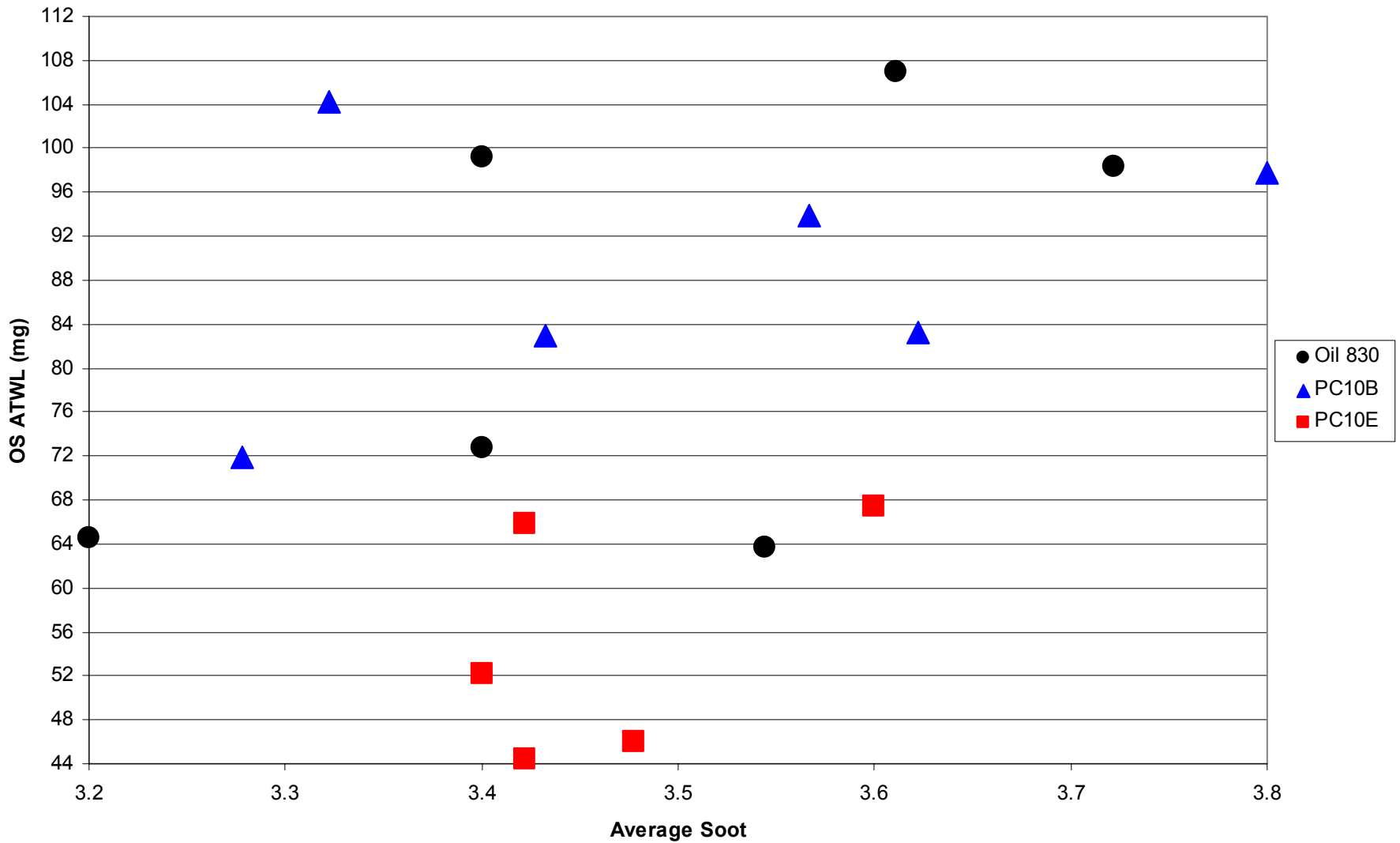
- $ATWL = f(\text{Lab}, \text{Stand}(\text{Lab}), \text{Oil}, \text{Avg Soot})$ 
  - Oil Discrimination (Overall p-value=0.005)
    - PC10E Lower than Other Oils
  - Lab Differences (Overall p-value=0.02)
    - Lab B Higher than Lab G
    - Stand within Lab Effects (Overall p-value=0.02)
  - Correction for Average Soot
    - Slope=76 (Correct Back to 3.50% Soot)
    - $SA\ ATWL = ATWL - 76 * (\text{AvgSoot} - 3.50)$



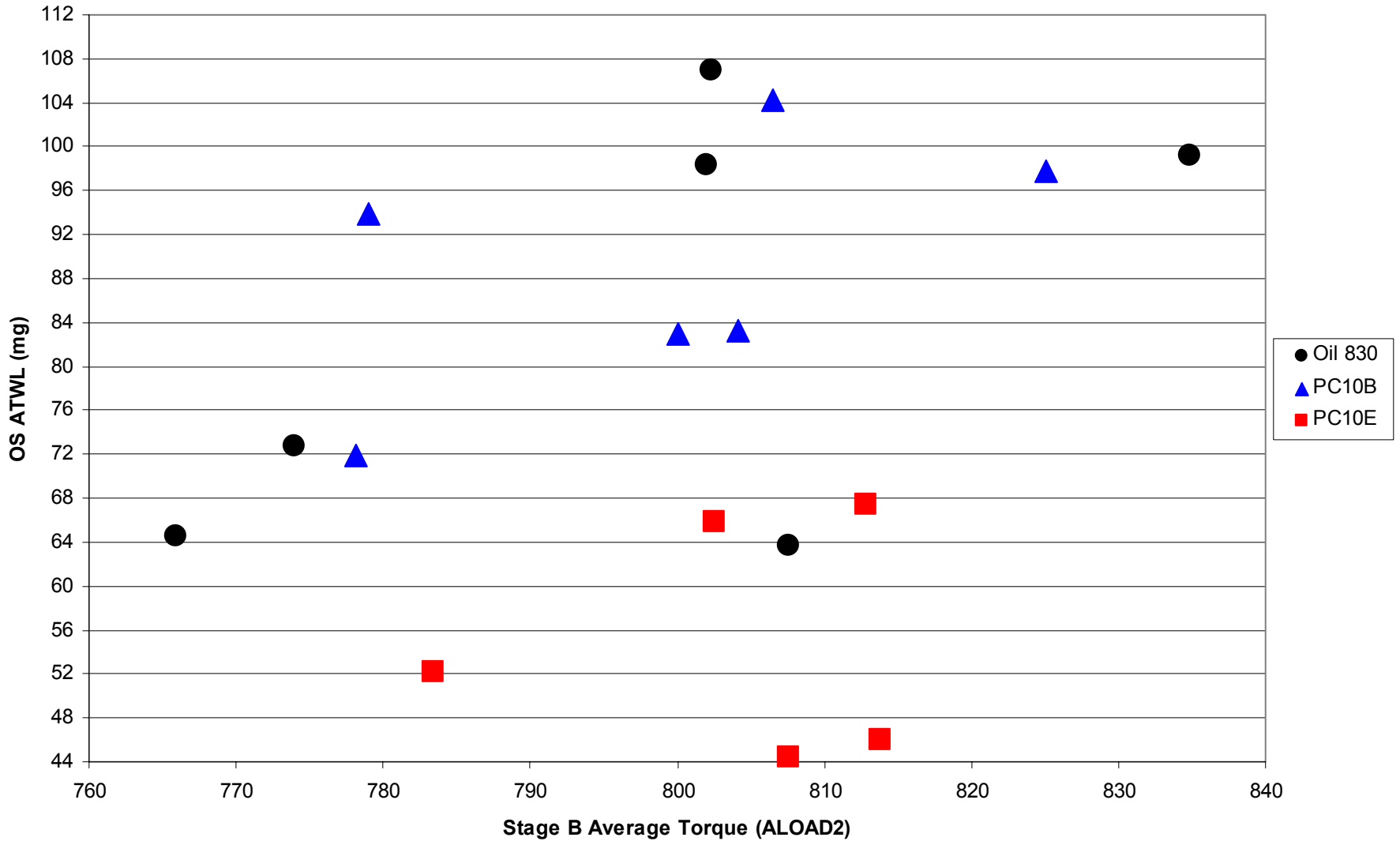
# Tukey Adjusted p-Values

	Oil 830-2	PC10B	PC10E
Tappet Wear (mg) Soot Adj	LS Mean = 88.23 StdErr = 3.766	LS Mean = 93.47 StdErr = 3.710	LS Mean = 67.54 StdErr = 4.794
Oil 830-2		0.61	<b>0.01</b>
PC10B	0.61		<b>0.005</b>
PC10E	<b>0.01</b>	<b>0.005</b>	

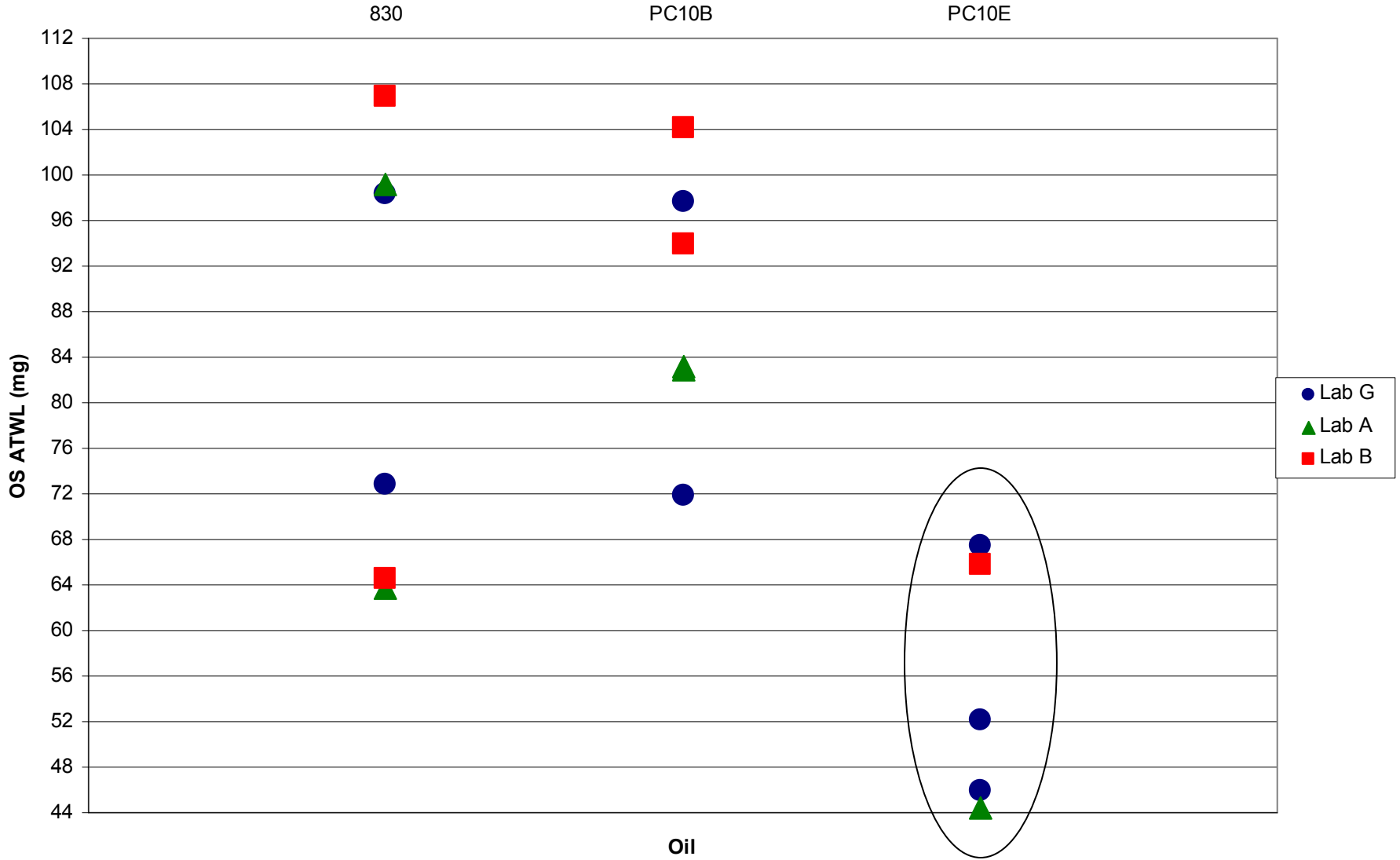
### OS Tappet Weight Loss as a Function of Oil and Soot



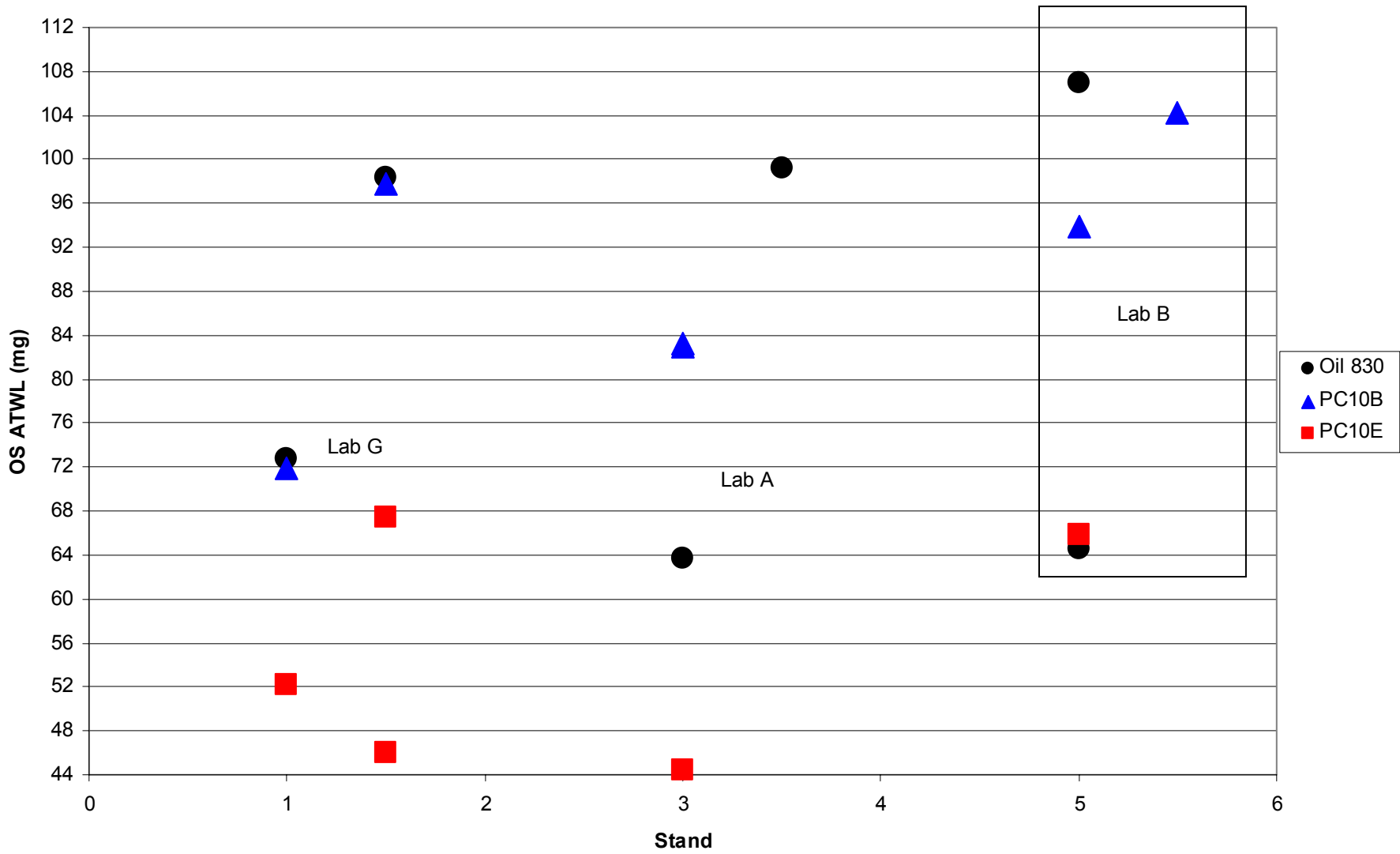
### OS Tappet Weight Loss as a Function of Stage B Average Torque



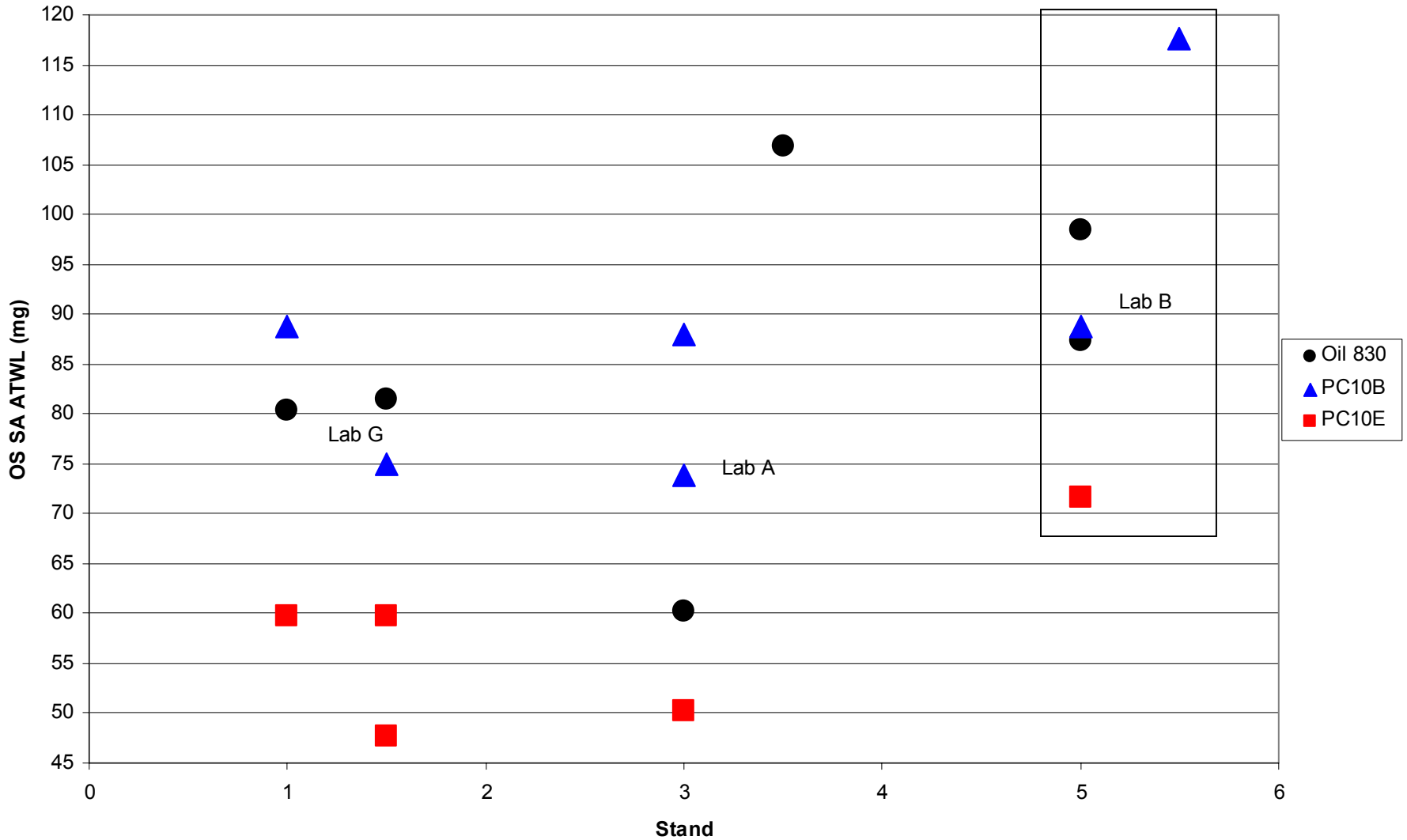
### OS Tappet Weight Loss as a Function of Oil and Lab



### OS Tappet Weight Loss as a Function of Stand and Oil



### OS Soot Adjusted Tappet Weight Loss as a Function of Stand and Oil



# Average Camshaft Wear

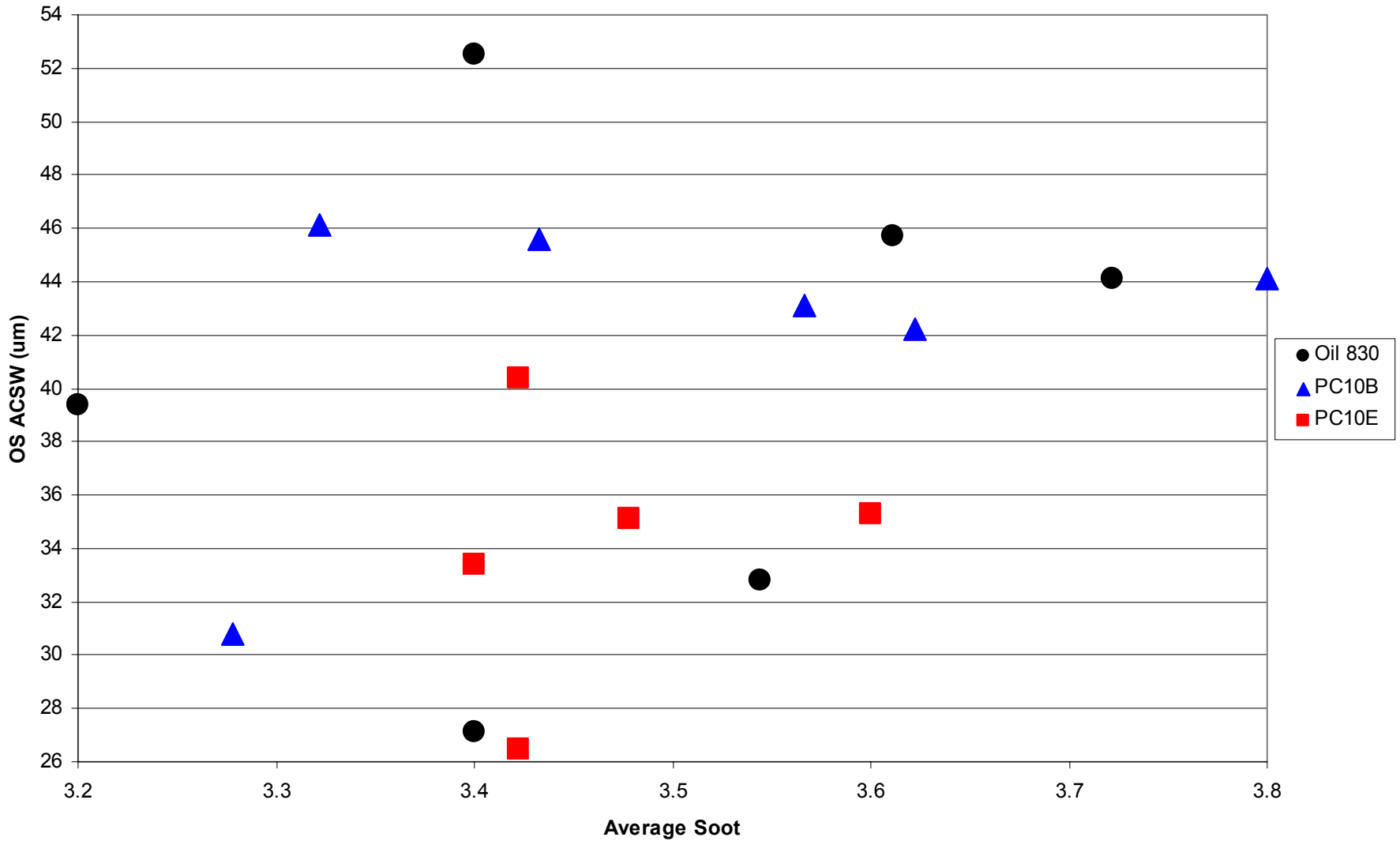
- $ACSW = f(\text{Lab}, \text{Stand}(\text{Lab}), \text{Oil})$ 
  - Some Evidence of Oil Discrimination ( $p=0.08$ )
    - PC10B versus PC10E ( $p=0.07$ )
  - Lab Differences (Overall  $p$ -value= $0.05$ )
    - Lab G Lower than Other Labs
    - Stand within Lab Effects (Overall  $p$ -value= $0.02$ )
  - Other Possible Effects
    - Stage B Average Torque

# Tukey Adjusted p-Values

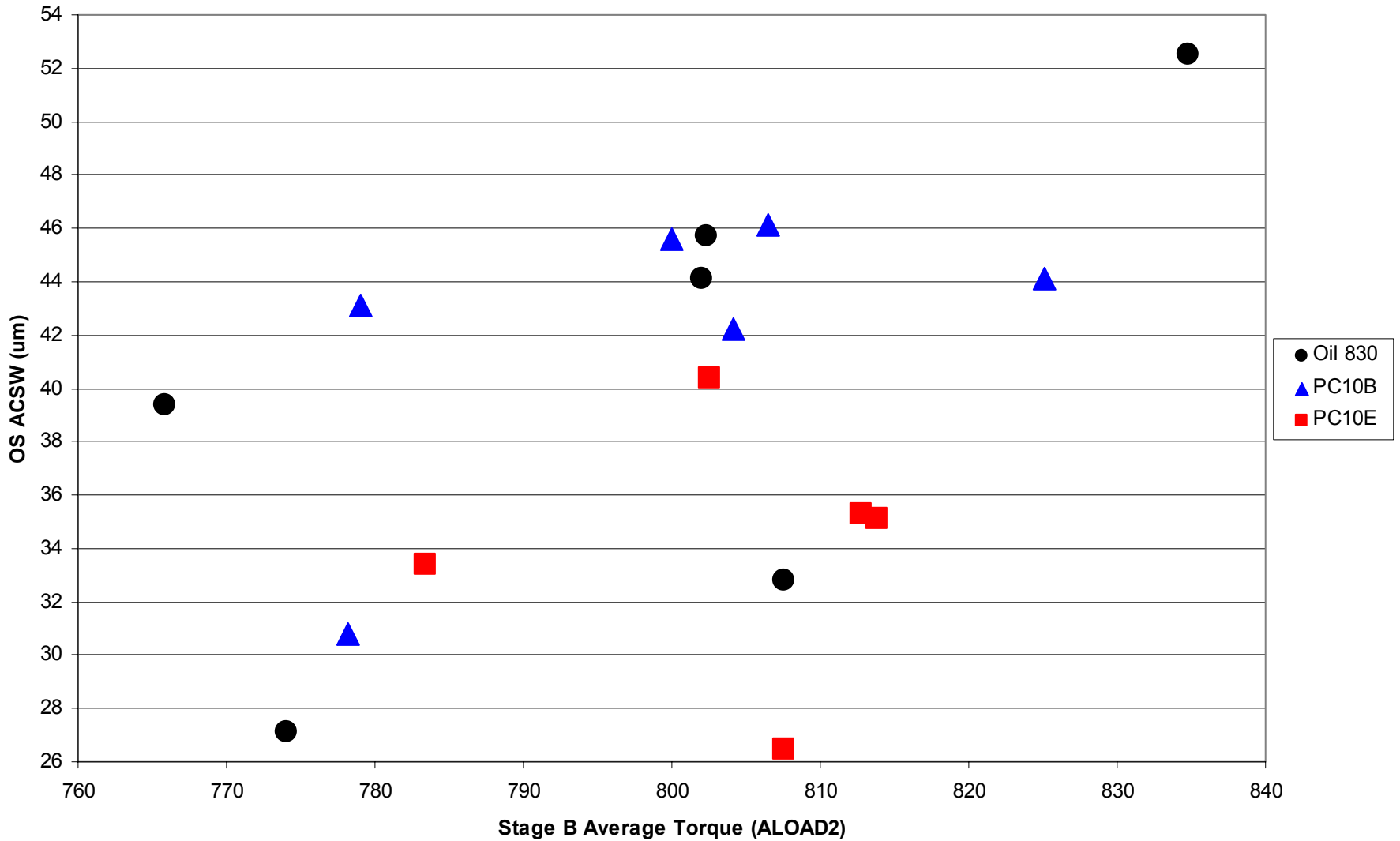
	Oil 830-2	PC10B	PC10E
Camshaft Wear (um)	LS Mean = 40.2 StdErr = 2.137	LS Mean = 44.85 StdErr = 2.137	LS Mean = 36.86 StdErr = 2.473
Oil 830-2		0.33	0.54
PC10B	0.33		<b>0.07</b>
PC10E	0.54	<b>0.07</b>	



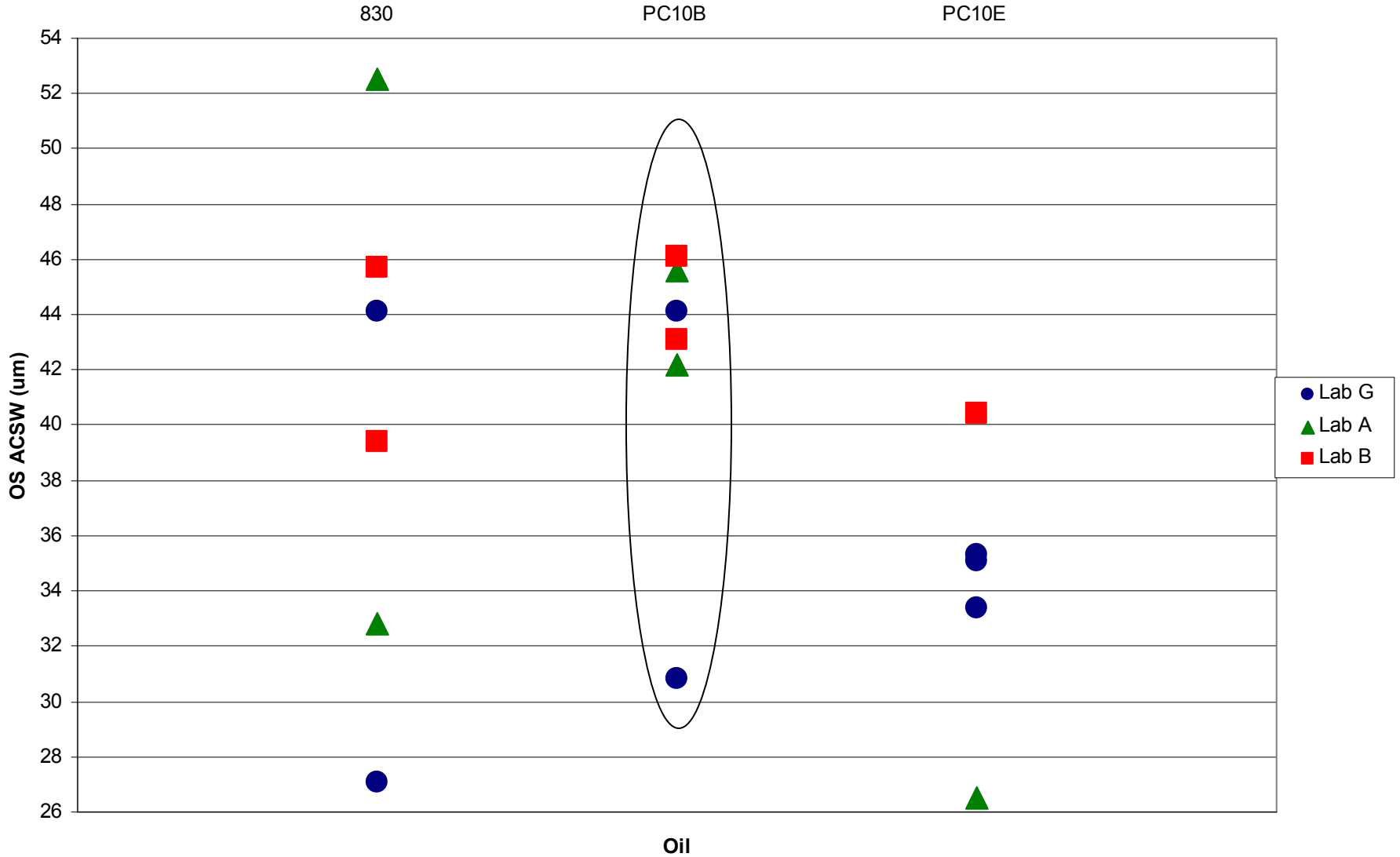
### OS Average Camshaft Wear as a Function of Oil and Soot



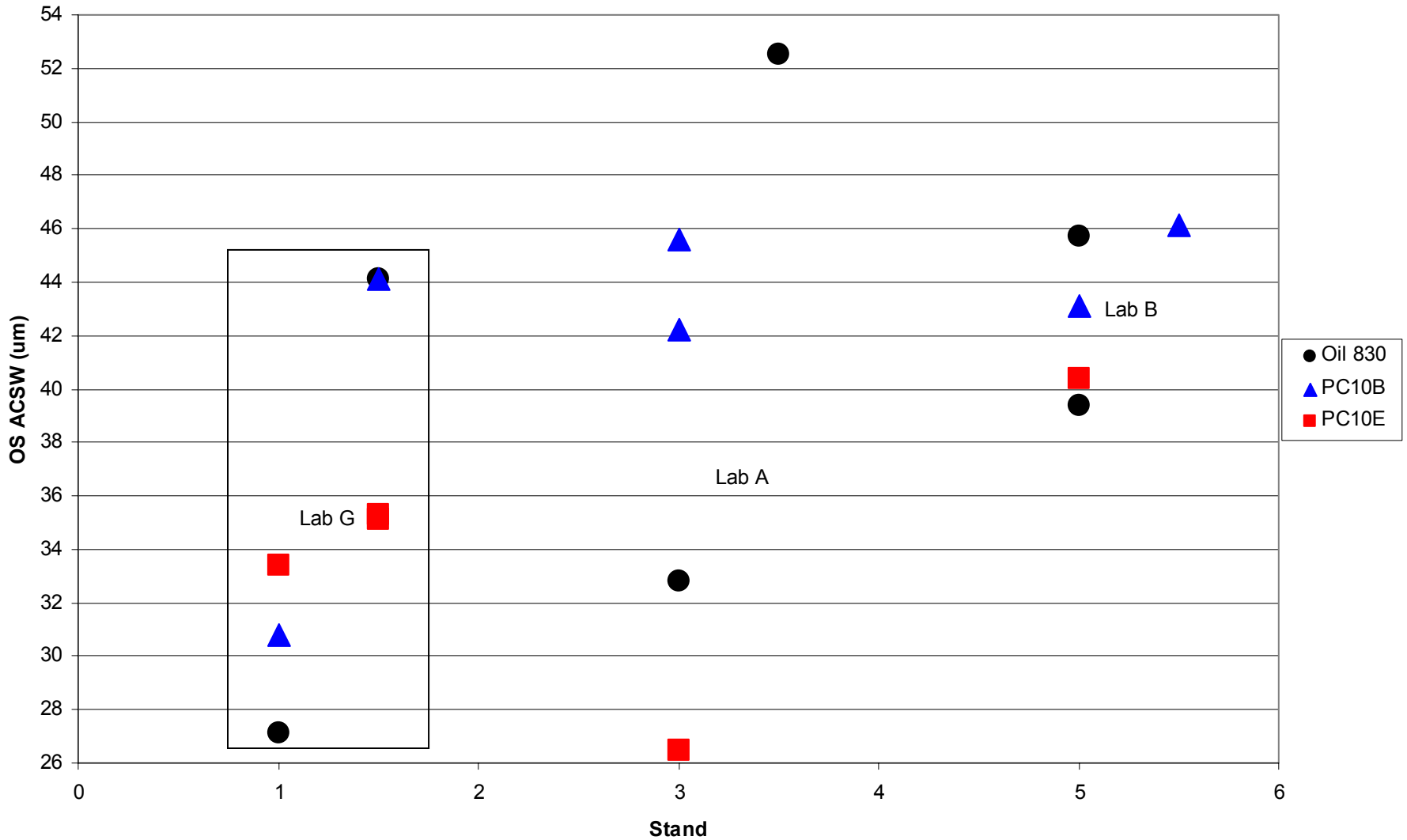
### OS Average Camshaft Wear as a Function of Stage B Average Torque



### OS Average Camshaft Wear as a Function of Oil and Lab



### OS Average Camshaft Wear as a Function of Stand and Oil



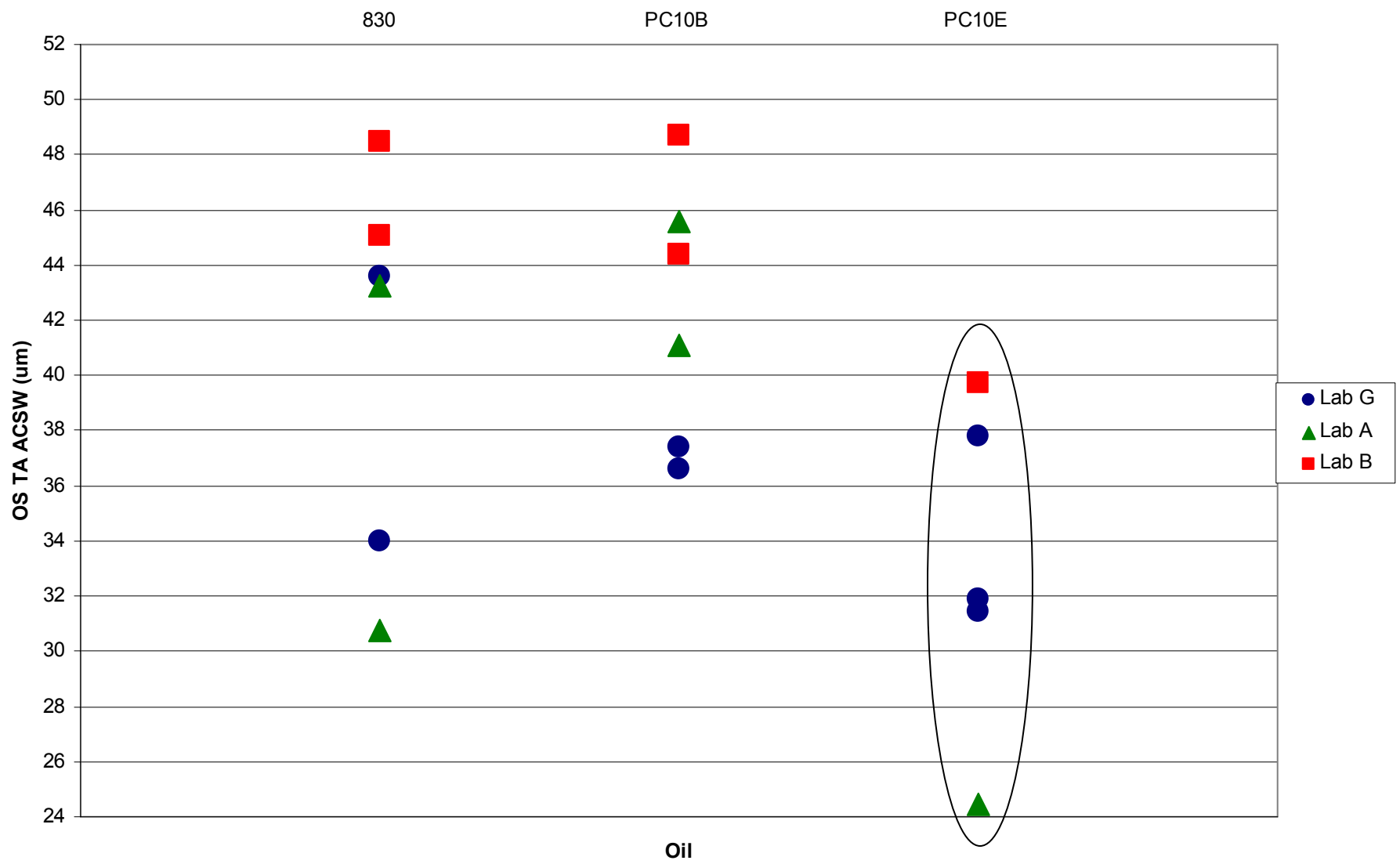
# Average Camshaft Wear

- $ACSW = f(\text{Lab, Oil, Stage B Avg Torque})$ 
  - Some Evidence of Oil Discrimination ( $p=0.06$ )
    - PC10B versus PC10E ( $p=0.06$ )
  - Some Evidence of Lab Differences ( $p=0.06$ )
    - Lab B Higher than Other Labs
  - Torque Correction
    - Slope=0.26629 (Correct Back to 800)
    - $SA ACSW = ACSW - 0.26629 * (\text{Torque} - 800)$

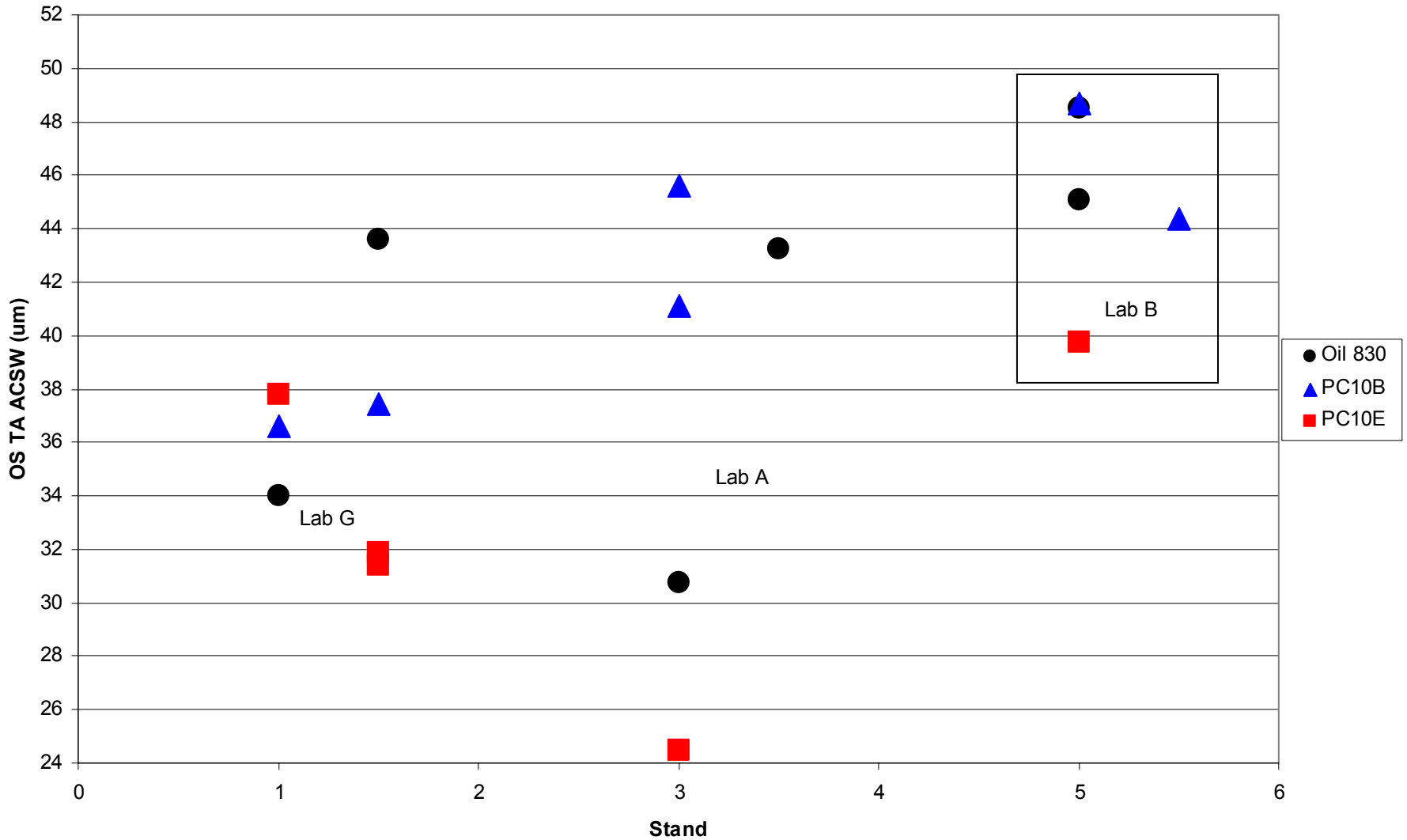
# Tukey Adjusted p-Values

	Oil 830-2	PC10B	PC10E
Camshaft Wear (um)	LS Mean = 40.86 StdErr = 2.082	LS Mean = 42.29 StdErr = 2.077	LS Mean = 33.94 StdErr = 2.409
Oil 830-2		0.88	0.12
PC10B	0.88		<b>0.06</b>
PC10E	0.12	<b>0.06</b>	

### OS Torque Adjusted Average Camshaft Wear as a Function of Oil and Lab



### OS Torque Adjusted Average Camshaft Wear as a Function of Stand and Oil





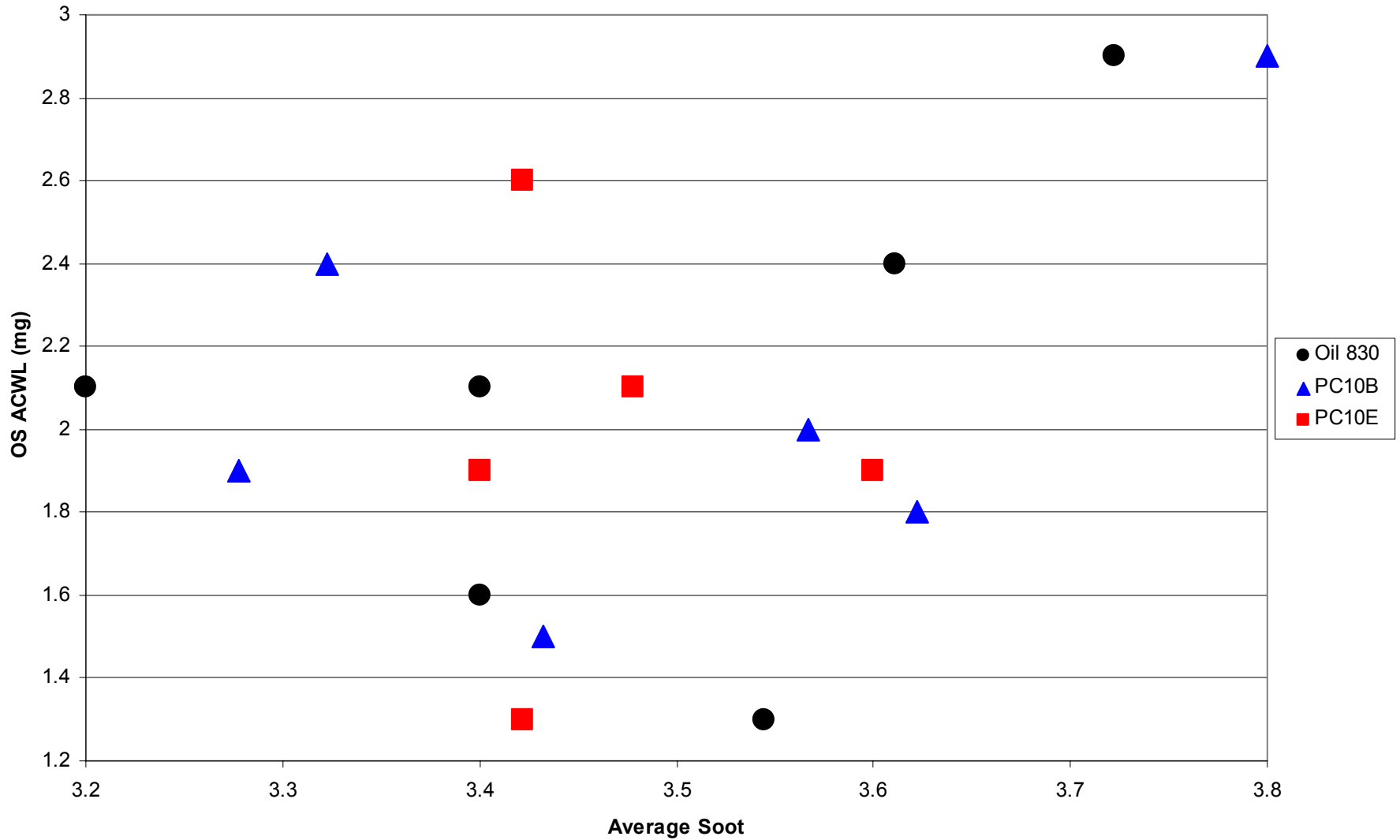
# Average Crosshead Mass Loss

- $ACWL = f(\text{Lab}, \text{Oil}, \text{Avg Soot})$ 
  - No Oil Discrimination (Overall p-value=0.85)
  - Lab Differences (Overall p-value=0.02)
    - Lab A Lower than Other Labs
    - No Stand within Lab Effects
  - Correction for Average Soot
    - Slope=1.3 (Correct Back to 3.50% Soot)
    - $SA\ ACWL = ACWL - 1.3 * (\text{AvgSoot} - 3.50)$

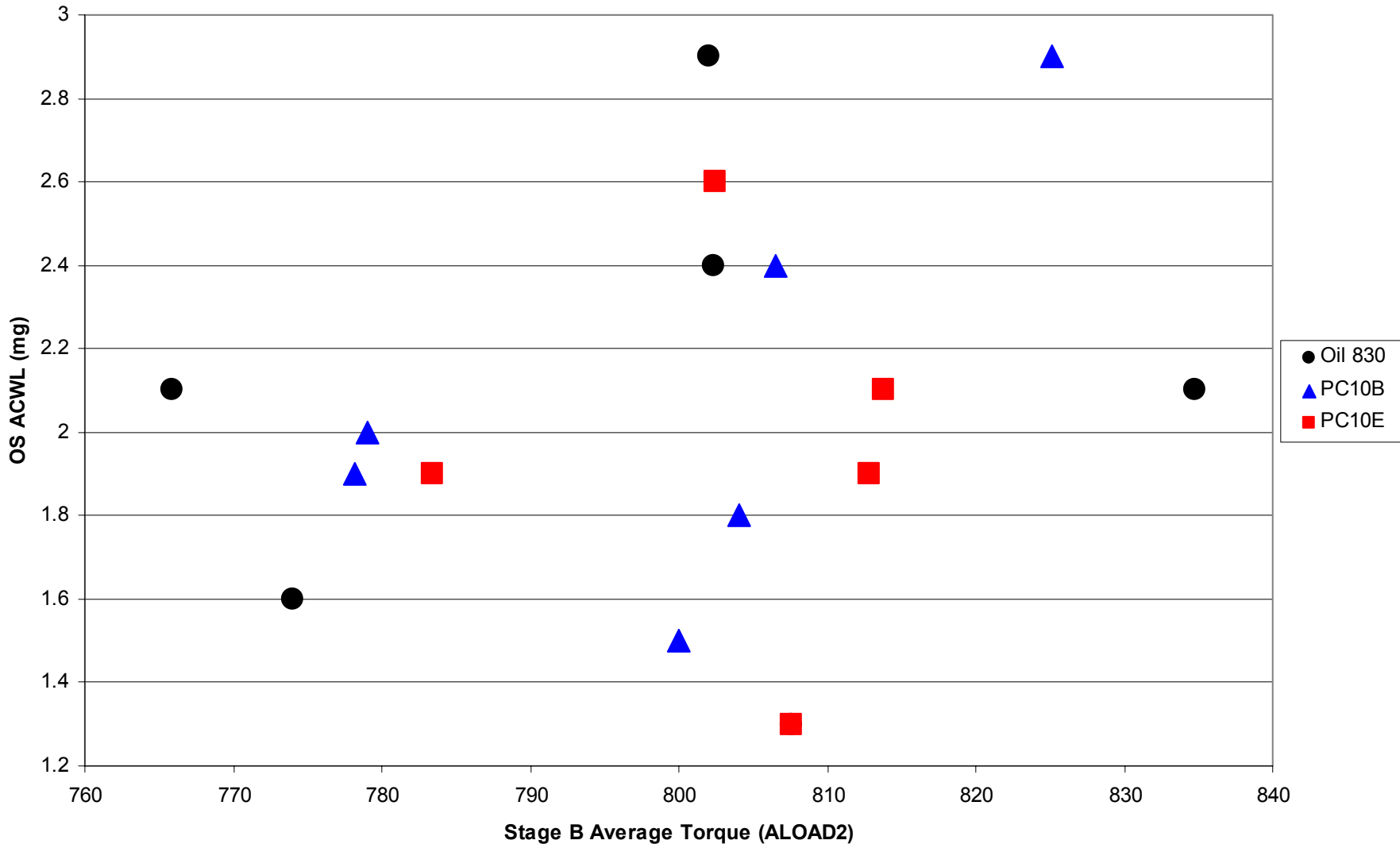
# Tukey Adjusted p-Values

	Oil 830-2	PC10B	PC10E
XHead Wear (mg) Soot Adj	LS Mean = 2.072 StdErr = 0.1559	LS Mean = 2.057 StdErr = 0.1564	LS Mean = 1.944 StdErr = 0.1803
Oil 830-2		0.99	0.85
PC10B	0.99		0.89
PC10E	0.85	0.89	

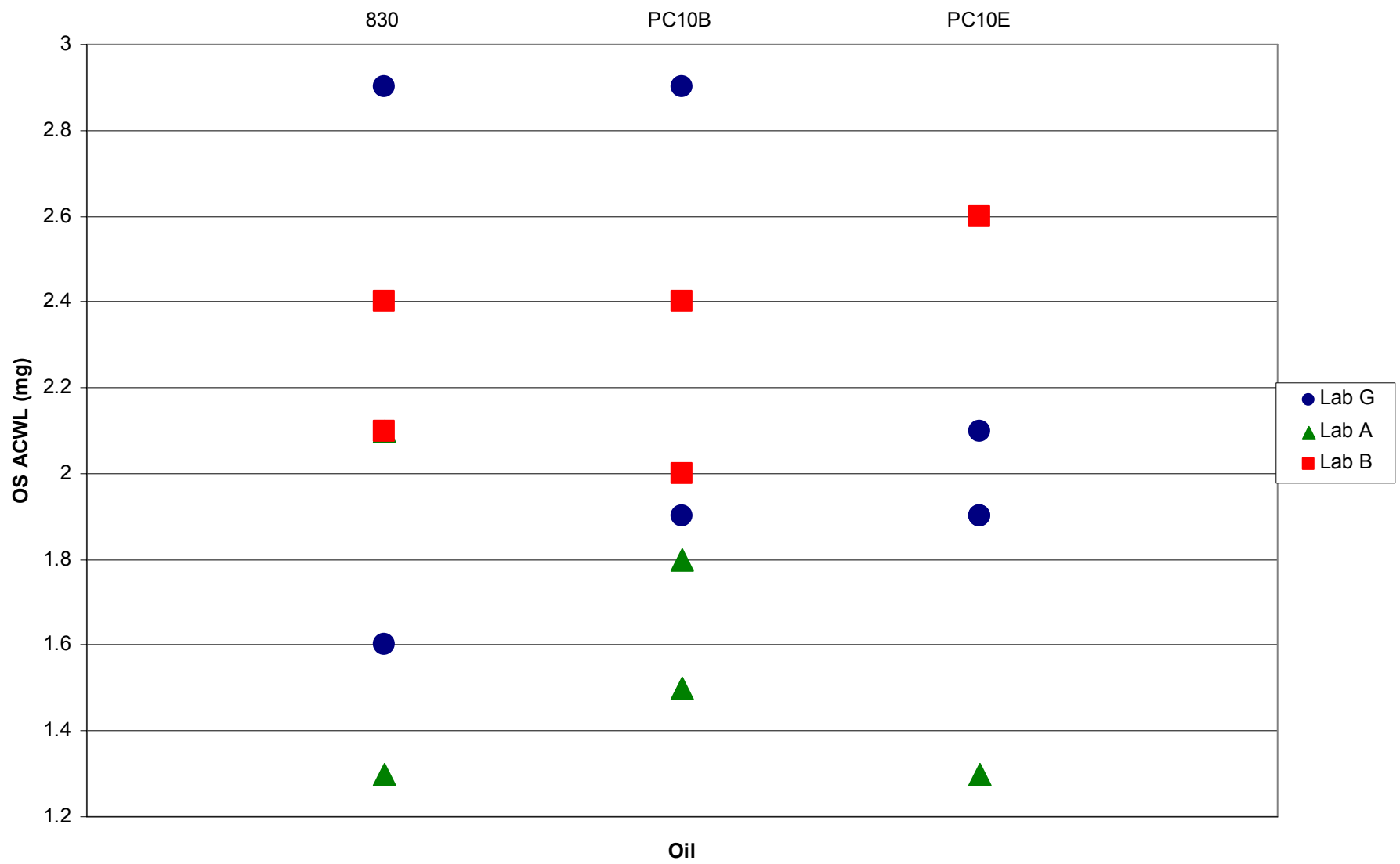
### OS Average Crosshead Mass Loss as a Function of Oil and Soot



### OS Average Crosshead Mass Loss as a Function of Stage B Average Torque



### OS Average Crosshead Mass Loss as a Function of Oil and Lab



### OS Average Crosshead Mass Loss as a Function of Stand and Oil

