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Falex Tribology N.V.
Rotselaar, Belgium

Tribology and
Petroleum Test
Equipment for
Over 80 Years

Company: **B4C Technologies**
Date: November 29, 2011
Technician: T. LeValley

Page: 1
Project No. 11-168
Test No. 0109993
Test Date: November 28, 2011

Method: ASTM D 2714, Calibration and Operation of the Falex Block on Ring Test Machine

Machine: Falex Block on Ring Test Machine
Serial No. 9-001-330-0437-7

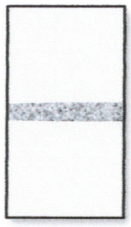
TEST PARAMETERS	
Speed (rpm):	72
Temperature (°C):	43.3
Load (lb):	150
Duration (cycles):	5000
Lubricant ID:	**ASTM D2714 Calibration Fluid**
Falex TL No.	3137

TEST SPECIMENS	
Block ID:	**1018-1**
Falex TL No.	4053
Material:	as supplied
Finish (rms):	as supplied
Hardness (Rc):	as supplied
Ring ID:	**1018-1 Steel**
Falex TL No.	4053
Material:	as supplied
Finish (rms):	as supplied
Hardness (Rc):	as supplied

TEST RESULTS

MASS DATA

Mass (g)	Block	Ring
Initial	7.7482	22.4104
Final	7.7469	22.4103
Loss	**0.0013**	**0.0001**



Block Scar

BLOCK SCAR DATA

Measurement 1 (mm):	0.933
Measurement 2 (mm):	1.101
Measurement 3 (mm):	1.091
Average Scar (mm):	**1.042**
Standard Dev (mm):	0.077
Coeff of Var (%):	7.391
Volumetric (mm^3):	0.0342

FRICTION DATA

Cycles	Friction Force (lb)	Coefficient of Friction
0	2.9	~
200	20.5	0.137
400	20.6	0.138
600	20.1	0.134
4500	**19.8**	0.132
5000	20.2	0.134
	AVERAGE CoF:	**0.135**

COMMENTS:

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Company:	**B4C Technologies**	Page:	2
Date:	November 29, 2011	Project No.	11-168
Technician:	T. LeValley	Test No.	0109994
		Test Date:	November 28, 2011

Method: ASTM D 2714, Calibration and Operation of the Falex Block on Ring Test Machine

Machine: Falex Block on Ring Test Machine
Serial No. 9-001-330-0437-7

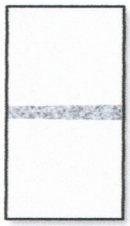
TEST PARAMETERS	
Speed (rpm):	72
Temperature (°C):	43.3
Load (lb):	150
Duration (cycles):	5000
Lubricant ID:	**ASTM D2714 Calibration Fluid**
Falex TL No.	3137

TEST SPECIMENS	
Block ID:	**1018 w/B4C-1**
Falex TL No.	4054
Material:	as supplied
Finish (rms):	as supplied
Hardness (Rc):	as supplied
Ring ID:	**1018 w/B4C-1**
Falex TL No.	4054
Material:	as supplied
Finish (rms):	as supplied
Hardness (Rc):	as supplied

TEST RESULTS

MASS DATA

Mass (g)	Block	Ring
Initial	7.7534	22.4241
Final	7.7533	22.4240
Loss	**0.0001**	**0.0001**



Block Scar

BLOCK SCAR DATA

Measurement 1 (mm):	0.672
Measurement 2 (mm):	0.777
Measurement 3 (mm):	0.859
Average Scar (mm):	**0.769**
Standard Dev (mm):	0.077
Coeff of Var (%):	9.948
Volumetric (mm^3):	0.0138

FRICTION DATA

Cycles	Friction Force (lb)	Coefficient of Friction
0	2.5	~
200	19.1	0.127
400	19.4	0.129
600	19.7	0.132
4500	**19.7**	0.131
5000	20.3	0.136
	AVERAGE CoF:	**0.131**

COMMENTS:

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Company: **B4C Technologies**
Date: November 29, 2011
Technician: T. LeValley

Page: 3
Project No. 11-168
Test No. 0109995
Test Date: November 29, 2011

Method: ASTM D 2714, Calibration and Operation of the Falex Block on Ring Test Machine

Machine: Falex Block on Ring Test Machine
Serial No. 9-001-330-0437-7

TEST PARAMETERS	
Speed (rpm):	72/1000
Temperature (°C):	43.3
Load (lb):	150/+30 till failure
Duration (cycles):	5000/ @1min steps to failure
Lubricant ID:	**ASTM D2714 Calibration Fluid**
Falex TL No.	3137

TEST SPECIMENS	
Block ID:	**1018 -2**
Falex TL No.	4053
Material:	SAE 01 Tool Steel
Finish (rms):	4-8
Hardness (Rc):	27-33
Ring ID:	**1018-2**
Falex TL No.	4053
Material:	SAE 4620 Steel
Finish (rms):	6-12
Hardness (Rc):	58-63

TEST RESULTS

MASS DATA

Mass (g)	Block	Ring
Initial	7.7271	22.4346
Final	7.6129	22.5296
Loss	**0.1142**	**-0.0950**

Block Scar

BLOCK SCAR DATA

Measurement 1 (mm):	8.998
Measurement 2 (mm):	9.121
Measurement 3 (mm):	9.036
Average Scar (mm):	**9.052**
Standard Dev (mm):	0.051
Coeff of Var (%):	0.568
Volumetric (mm^3):	22.8990

FRICTION DATA

Cycles	Friction Force (lb)	Coefficient of Friction
0	2.6	~
200	21.3	0.142
400	21.4	0.143
600	21.7	0.145
4500	**21.5**	0.143
5000	21.3	0.142
	AVERAGE CoF:	**0.143**

COMMENTS: Test stopped due to extreme vibration on 1st load step and speed increase. Material transfer & galling.

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Page: 4
Project No. 11-168
Test No. 0109996
Test Date: November 29, 2011

Method: ASTM D 2714, Calibration and Operation of the Falex Block on Ring Test Machine

Machine: Falex Block on Ring Test Machine
Serial No. 9-001-330-0437-7

TEST PARAMETERS	
Speed (rpm):	72/1000
Temperature (°C):	43.3
Load (lb):	150/+30 till failure
Duration (cycles):	5000/ @1min steps to failure
Lubricant ID:	**ASTM D2714 Calibration Fluid**
Falex TL No.	3137

TEST SPECIMENS	
Block ID:	**1018 w/B4C - 2**
Falex TL No.	4054
Material:	as supplied
Finish (rms):	as supplied
Hardness (Rc):	as supplied
Ring ID:	**1018 w/B4C - 2**
Falex TL No.	4054
Material:	as supplied
Finish (rms):	as supplied
Hardness (Rc):	as supplied

TEST RESULTS

MASS DATA

Mass (g)	Block	Ring
Initial	7.7583	22.3839
Final	7.7557	22.3789
Loss	**0.0026**	**0.0050**

Block Scar

BLOCK SCAR DATA

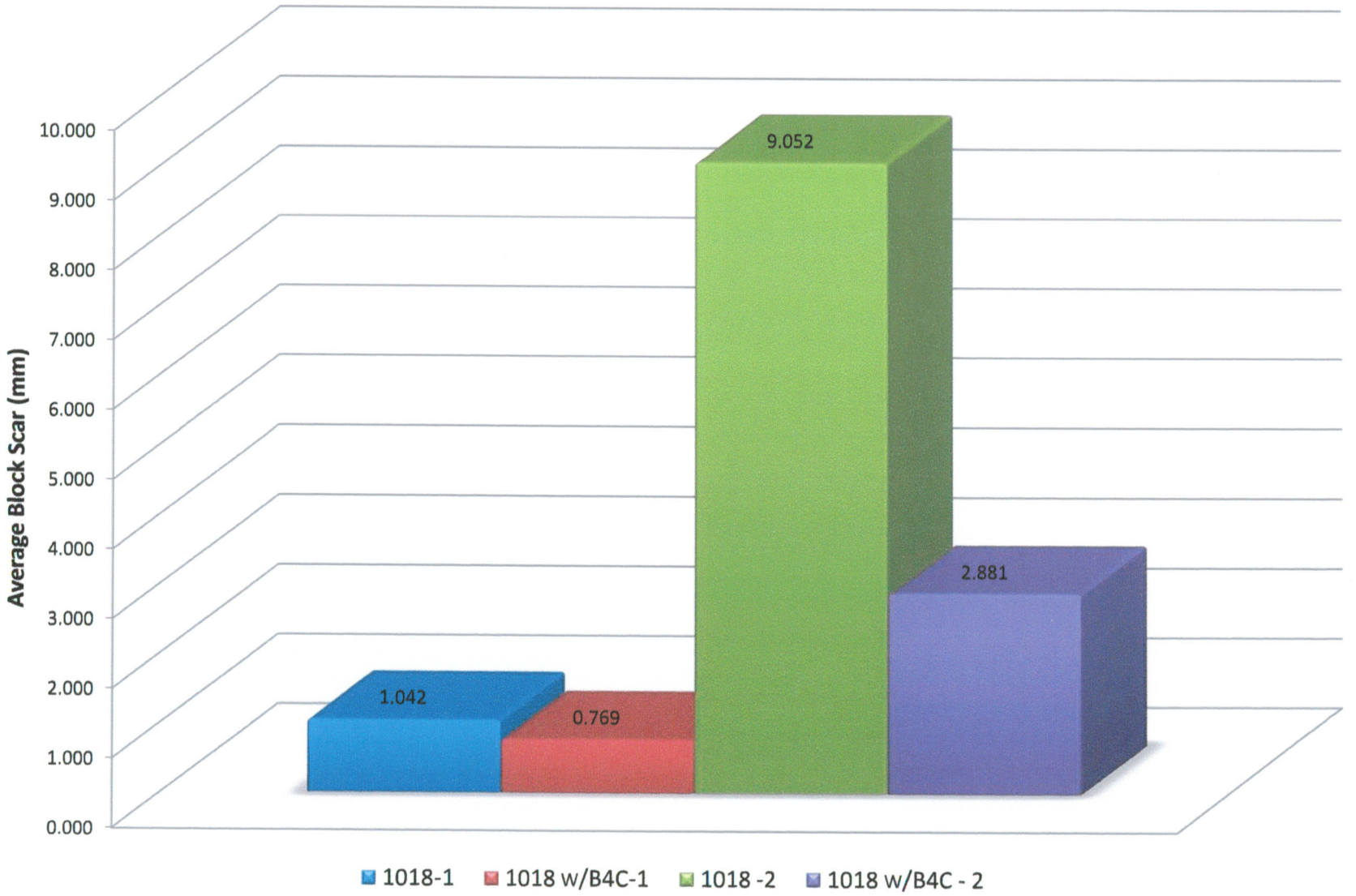
Measurement 1 (mm):	2.911
Measurement 2 (mm):	2.927
Measurement 3 (mm):	2.804
Average Scar (mm):	**2.881**
Standard Dev (mm):	0.055
Coeff of Var (%):	1.896
Volumetric (mm^3):	0.7245

FRICTION DATA

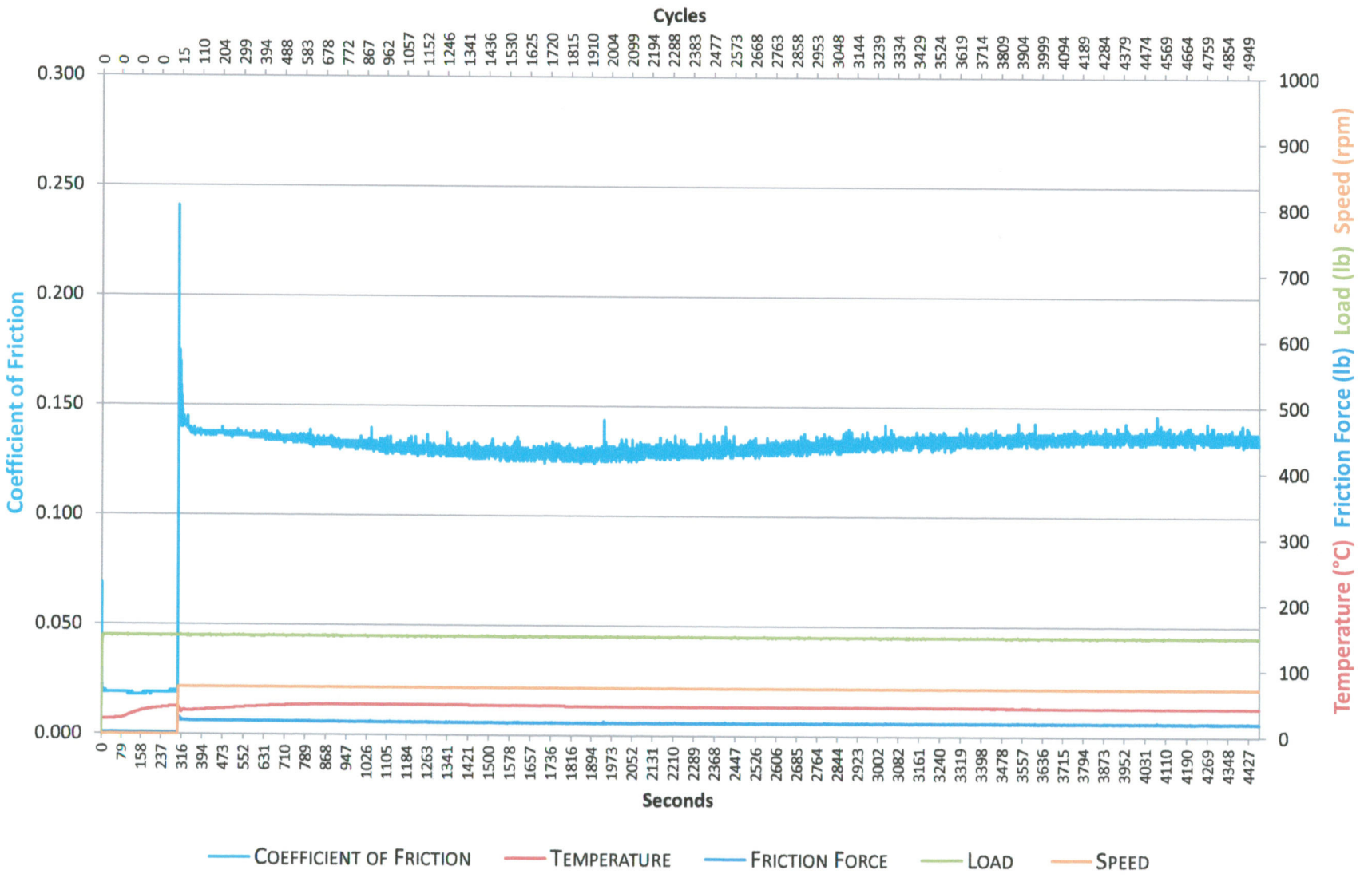
Cycles	Friction Force (lb)	Coefficient of Friction
0	2.6	~
200	19.2	0.128
400	19.6	0.131
600	19.8	0.132
4500	**19.7**	0.132
5000	20.3	0.135
	AVERAGE CoF:	**0.132**

COMMENTS:

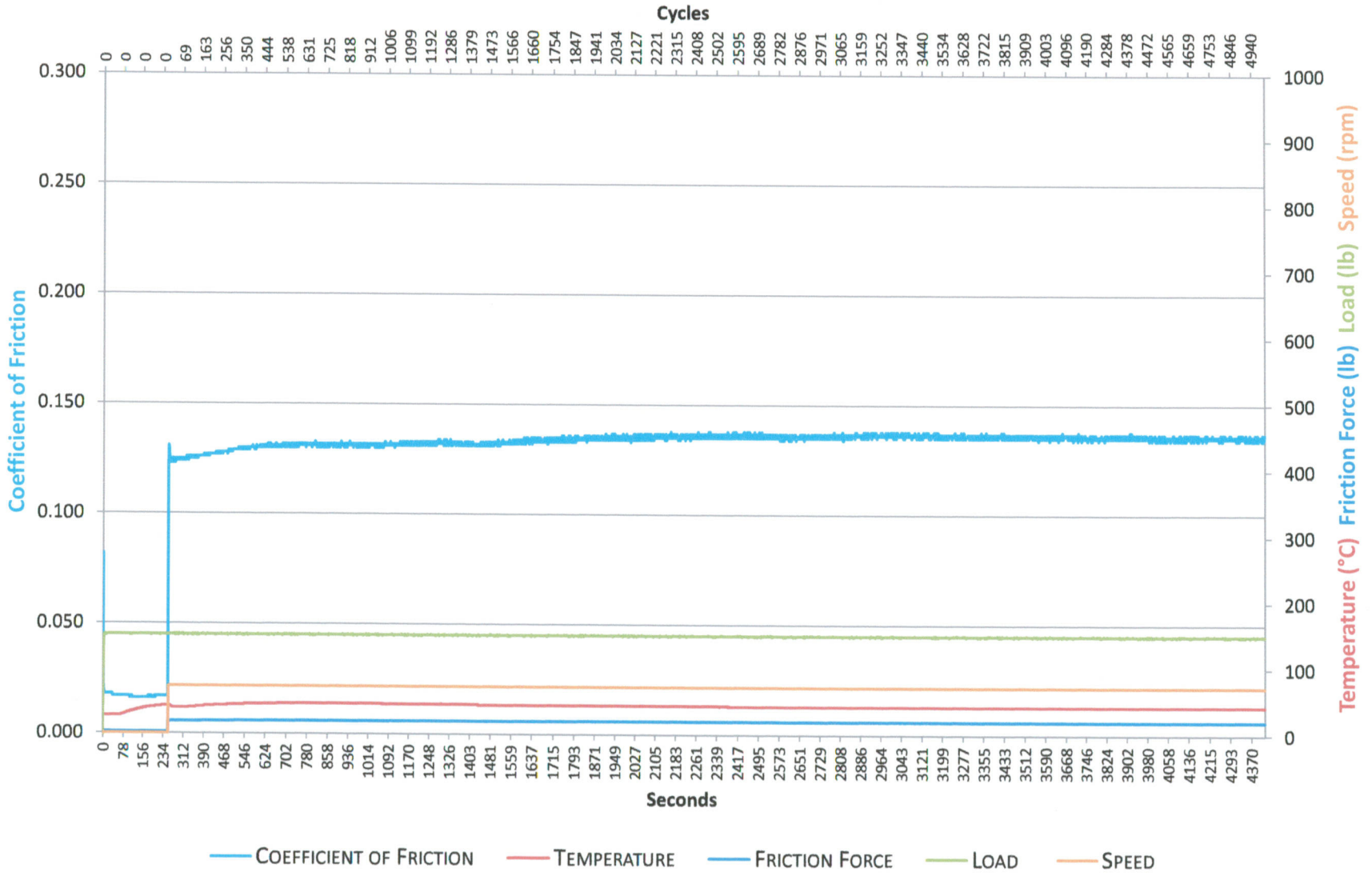
B4C Technologies Project 11-168 Test No. **0109993-996**
ASTM D 2714
Average Block Scar Summary



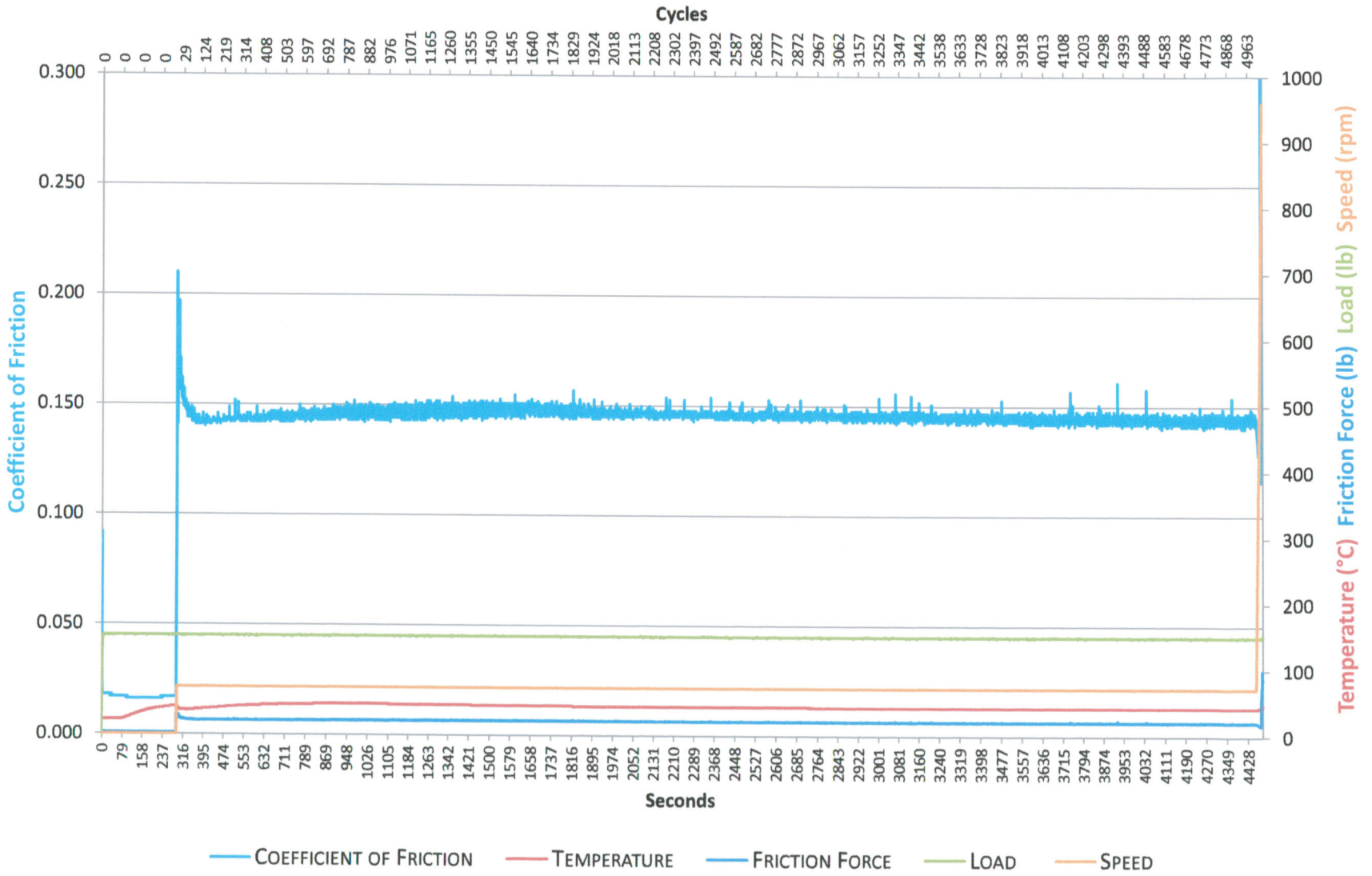
B4C Technologies Project 11-168 Test No. **0109993**
Specimen: **1018 Baseline** TL No. 4053
ASTM D 2714



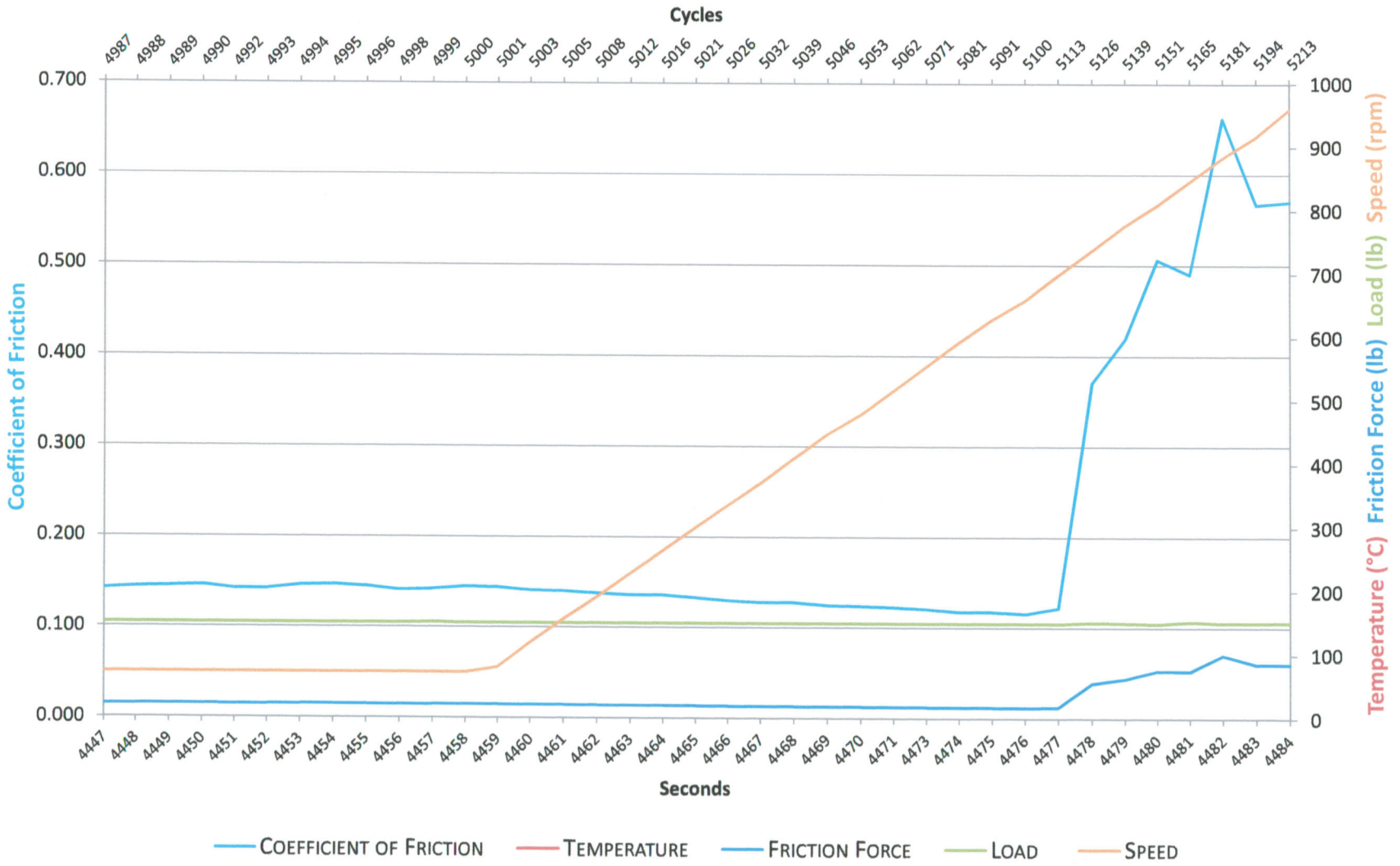
B4C Technologies Project 11-168 Test No. **0109994**
Specimen: **1018/B4C Baseline** TL No. 4054
ASTM D 2714



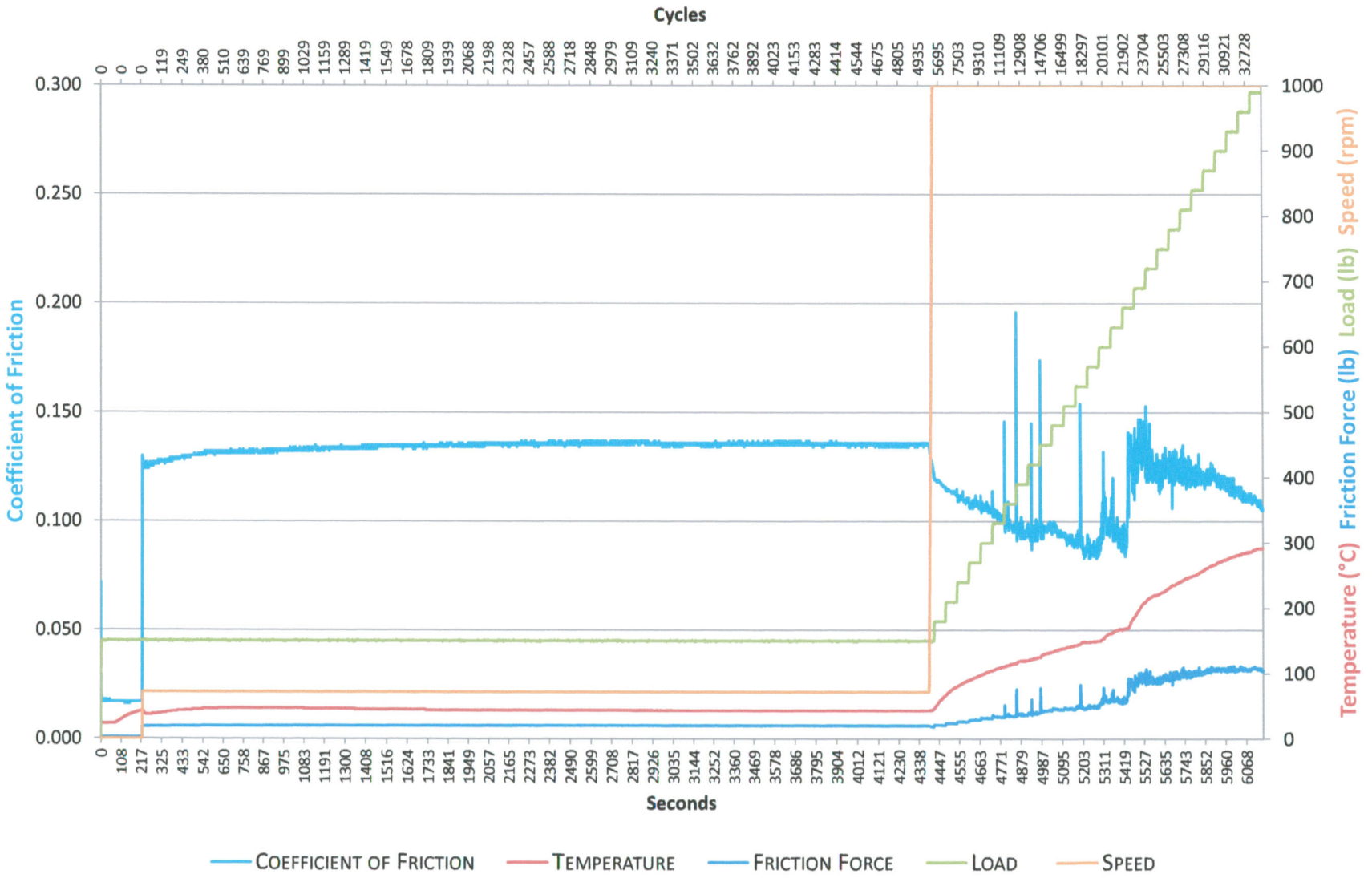
B4C Technologies Project 11-168 Test No. **0109995**
Specimen: **1018 - 2** TL No. 4053
ASTM D 2714



B4C Technologies Project 11-168 Test No. **0109995**
Specimen: **1018 - 2** TL No. 4053
Failure Sequence-End of Test
ASTM D 2714



B4C Technologies Project 11-146 Test No. **0109996**
Specimen: **1018 w/B4C-2** TL No. 4054
ASTM D 2714

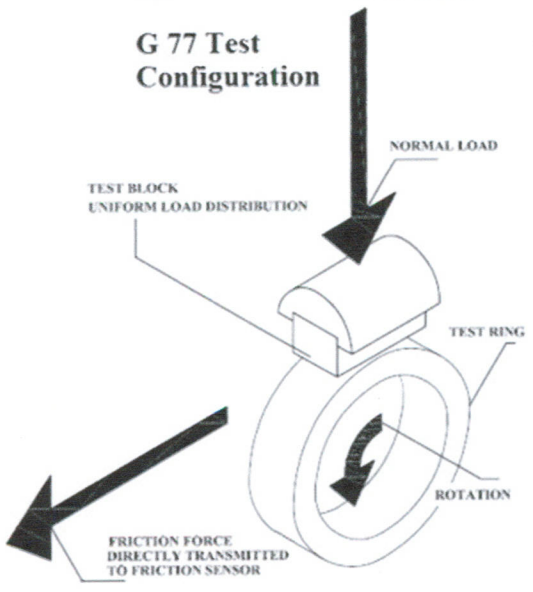


Falex Block on Ring study; conclusions

Scope:

B4C Technologies LLC, commissioned Falex Cooperation to conduct a study to measure the wear resistance of our boron diffusion process under extreme conditions. Falex is known throughout the world as the leading independent authority in the study of wear and lubrication.

After several conversations with Falex engineers, we selected ASTM-G77 (block on ring) as the test procedure. We also selected the least expensive steel for testing as one of the major attributes of the B4C process is the ability to reduce manufacturing costs in many cases by substituting high-end / exotic alloys with inexpensive steel by treating with the B4C process. As a result, all of the test specimens were made of SAE-1018 steel aka, mild steel.



The illustration above depicts how the test is conducted; a stationary Test Block is in contact with a Rotating Ring while the block is under a highly controlled load.

The ASTM specification G-77 allows the flexibility of choosing which surface to treat; block, ring or both. The load can also vary between 30 pounds and 1,000 pounds and the rotating speed of the ring can vary between 72-RPM and 1,000-RPM.

As a means of a direct comparison, we elected to treat both the block and ring and compare the combination against a non-treated block and ring as control. Four pairs, (4

test blocks and 4 test rings) all certified to be made of SAE-1018 mild steel were purchased from Falex.

Two pairs were treated with the B4C Technologies process converting the outer 300 microns +/- to Fe_2B both at the same time using the chemical slurry from the same batch to ensure identical treatment. The remaining 2 pairs were set aside and labeled as Control.

White mineral oil was used as the liquid as recommended by ASTM as a non-lubricating solvent.

Each test block and ring was thoroughly cleaned via an ultrasonic bath and weighed on a calibrated milligram scale. The "before and after weight was noted for each test specimen.

Test parameters;

Phase-1 For the first hour of testing the ring is rotating at 72-RPM against the stationary block. 150 pounds is added to the block as the load.

Phase-2 After one hour, the rotating speed is increased to 1,000-RPM while the load is increased by 30 pounds every 60 seconds until either a catastrophic failure occurs or 1,000 pounds of additional load is added.

The results;

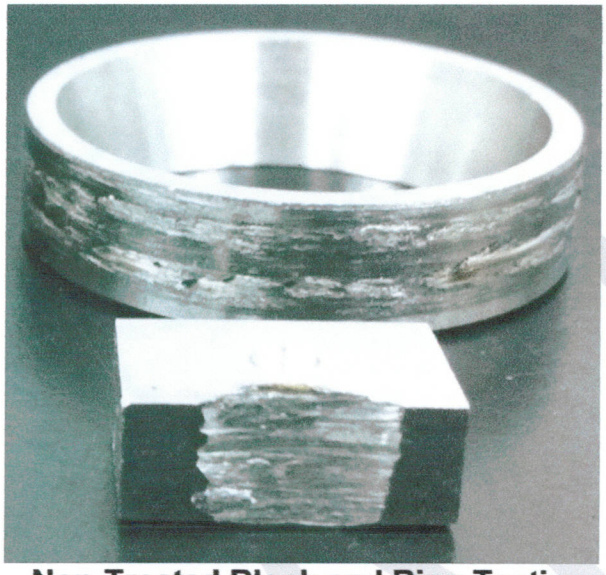
Phase-1,
The non-treated baseline control blocks lost an average of 13 milligrams
The treated blocks lost less than 1 milligram.
The non-treated block lost 13 times as much mass as the treated block after only one hour @ 150 pounds.

Phase-2
Baseline samples; after one hour the speed was increased to 1,000-RPM and the first increase in load (30 pounds) was added. Within 30 seconds a catastrophic failure occurred between the block and ring as severe adhesive wear (gaulling) was occurring causing the test machine to automatically disengage. See report for final measurements. .

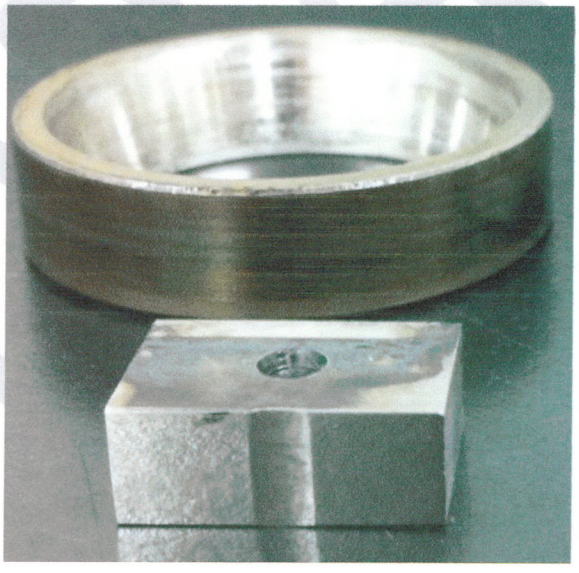
The treated samples; the test was suspended after successfully reaching both 1,000 RPM and 1,000 pounds of added load without **an increase in friction and no indication of adhesive wear or gaulling.**.

Results:

- The non-treated block lost 1142 milligrams of mass @180 pounds after only 1 hour 60 sec at which point catastrophically failed.
- The treated block lost only 26 milligrams of mass after successfully reaching the maximum 1,000 pounds and maximum 1,000 RPM after 2 hours



Non-Treated Block and Ring Testing



Treated Block and Ring after testing

1000 pounds load calculated to PSI (pounds per square inch) . The contacting surface area between the block and ring measured to be 0.769mm X 6.35mm = 4.88mm^2 or 0.03" X 0.250" = 0.0075in^2. 1000 lbs / 0.0075in^2 = 133,333 PSI