LETTER REPORT

FRICTION AND THERMAL IMAGING OF TREATED BEARING MATERIALS

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28 Sep 2012

Department of Energy (DOE) Proposal No. NFE-12-04150

Prepared Under DOE Contract # DE-AC05-00OR22725
Between
Department of Energy Oak Ridge Office
and
UT-Battelle, LLC

Friction and Thermal Imaging of Treated Bearing Materials

WFO for BTN, Chattanooga, TN

1. BACKGROUND

BETTER THAN NEW (BTN) has developed a proprietary process to apply a friction-reducing treatment to a variety of friction and wear-critical parts including tooling and engine components. Evidence obtained from field trials indicate the lubricity of this material, but systematic laboratory friction and wear data were not readily available. ORNL was approached by BTN to verify the performance of its treatment on a pair of common bearing steels under controlled conditions.

2. PURPOSE/OBJECTIVE

The purpose of this work was to determine friction coefficients of a proprietary treatment under sliding wear conditions when the treatment is used on one or both surfaces of an alloy steel couple, and compare the results to non-treated steel tested under the same conditions. In addition, an infrared camera was used in an attempt to detect differences in frictional heating due to sliding with and without the treatment.

3. TEST MATRIX and MATERIALS

ORNL obtained alloy steels and machined them to fit ORNL's Variable Load Bearing Tester (VLBT) which was designed to simulate variable loads and contact pressures as might be experienced by an internal combustion engine component during operation. After machining in a condition typical of engine applications, BTN applied a friction-reducing treatment to certain test specimens in order to investigate the following combinations of sliding conditions:

<u>Contact geometry:</u>	flat plate pressed upward against a rotating cylindrical shaft.
<u>Step-loading single cycle</u>:	20, 30, 40, 50, 40, 30 N per cycle
<u>Time for each load step in the cycle</u>:	10 s
<u>Cycles of loading per experiment</u>:	5
<u>Total sliding distance per experiment</u>:	30 m
<u>Sliding speed</u>:	0.1 m/s
<u>Repeats</u>:	Caution: It is recognized that with only one test per combination, the repeatability of these results cannot be established.
<u>Specimen Materials</u>:	The form and composition of the steels used as sliding partners is shown in Table 1.

Table 1. Form and Composition of Test Materials Used in this Project (continued on next page)

Item or Parameter	8620 Steel	4142 Steel
Source	McMaster Carr	McMaster Carr
Form	1.00” diameter precision rod	1.00 wide x 0.25 thick, pre-hardened precision ground flat stock
Test specimen	1.00” OD x 3.0” long rods (rotating specimen)	1.00 x 1.00 x 0.25” coupons (fixed specimen)
Composition (wt %)		
C	0.18 – 0.23	0.38 – 0.46
Mn	0.7 – 0.9	0.7 – 1.0
Si	0.20 – 0.35	0.15 – 0.30
P	0.04 max	0.035 max
S	0.04 max	0.040 max
Cr	0.4 – 0.6	0.8 – 1.15
Mo	0.15 – 0.25	0.15 – 0.25
V	-	0.03 max
Ni	0.4 – 0.7	-

Surface finish and list of runs. Measurements of the as-received cylinders and flat specimens indicated arithmetic average roughness (Ra) and ten-point height (Rz) are given in Table 2. The runs conducted using the specimens provided without further treatment or cleaning, are listed in Table 3. All runs produced data on normal force, friction force, and temperature (by IR camera measurements).

Table 2. Surface Roughness of As-Received, Non-coated Specimens

Specimen	Ra (μm)	Rz (μm)
Cylinder (non-coated)	0.028	0.20
Flat (non-coated)	0.048	0.49

Table 3. Test Runs, Treatments*, and Run Numbers

Run number	Cylinder Specimen	Flat Specimen
VLBT-60	Not treated	Not treated
VLBT-61	Treated	Treated
VLBT-63	Treated	Not treated

4. RESULTS

4.1 Friction Results.

Self-mated tests. Figure 1 shows the load spectrum and the corresponding friction coefficients for the first cycle for run number VLBT 60, and Figure 2 shows the last cycle of the same test. In comparison, Figure

3 shows the first cycle of test VLBT-61 (both cylinder and flat specimen treated) and Figure 4 the last cycle of the same test. Clearly, the treated pair was less sensitive to changes in normal force.

Figure 4 shows the friction versus testing time behavior for last cycle of the non-treated couple, the treated-on-treated couple, and the treated rod on non-treated flat specimen couple. Clearly, the non-treated steel surfaces had much higher friction coefficient than the treated ones, and the couple with both sides treated performed the best of all three.

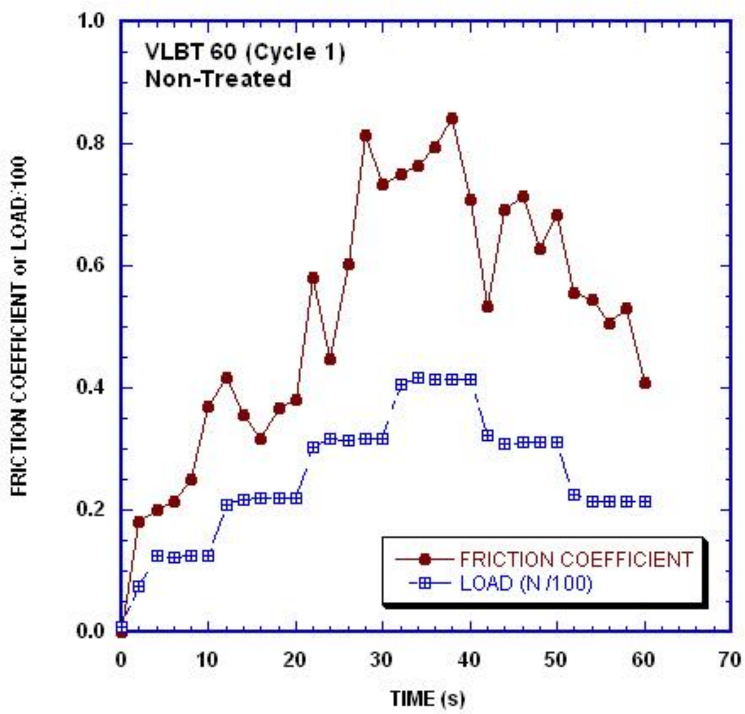


Figure 1. First cycle load and friction coefficient for the non-treated pair. Note that the load is divided by 100 to fit on the same vertical scale. The friction coefficient rises and falls similar to the load.

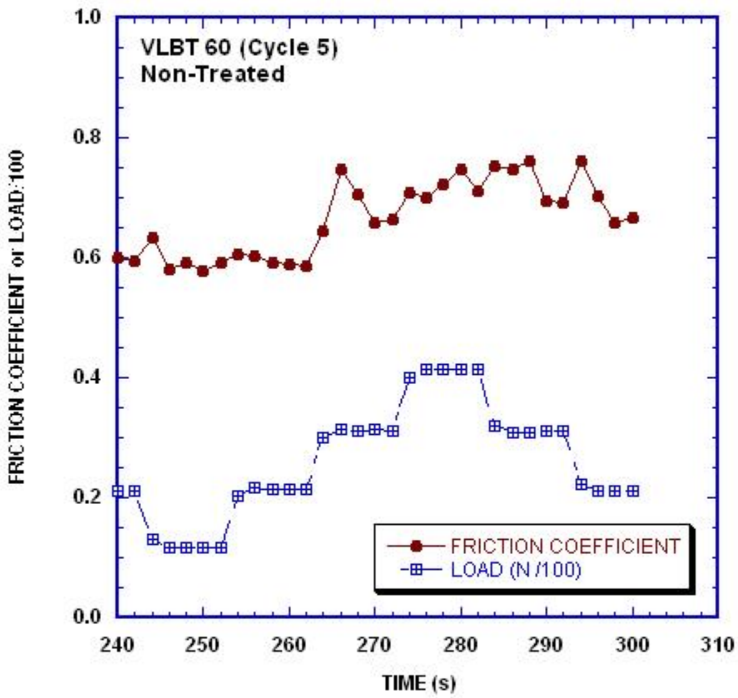


Figure 2. Fifth cycle load and friction coefficient for the non-treated pair. The friction is not as well correlated with the load after running-in.

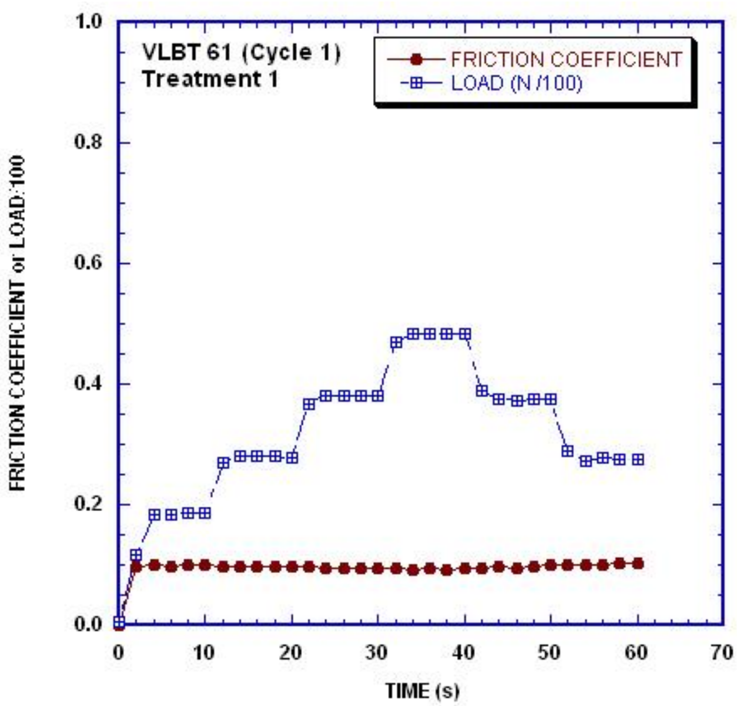


Figure 3. First cycle load and friction coefficient for self-mated Treatment 1. The friction coefficient does not follow the changes in load.

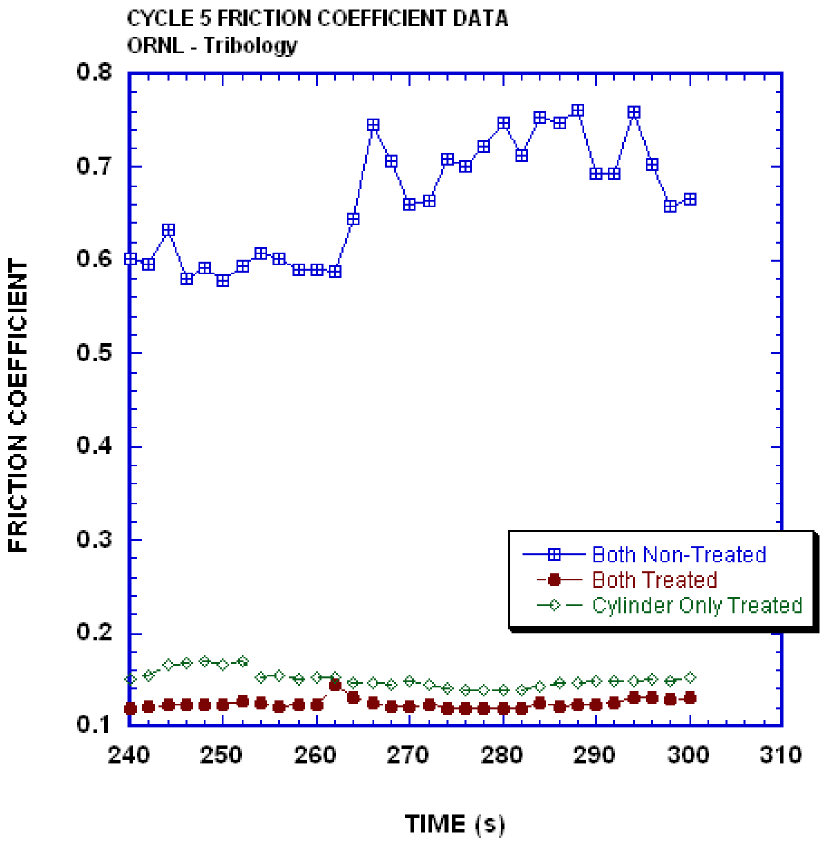
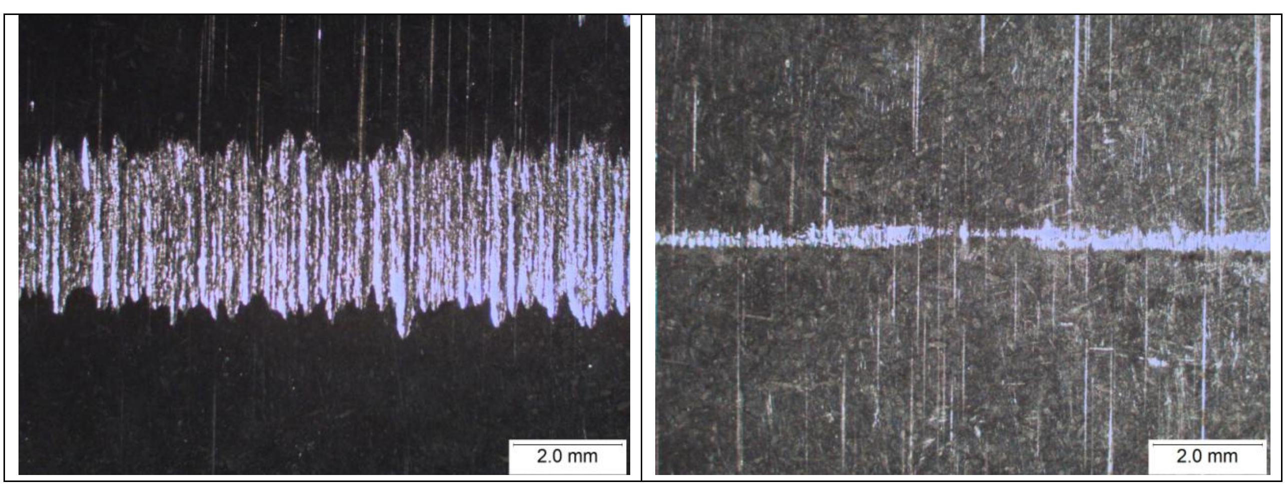


Figure 4. Comparison of friction versus time behavior of three conditions under the last cycle of a variable load friction test.

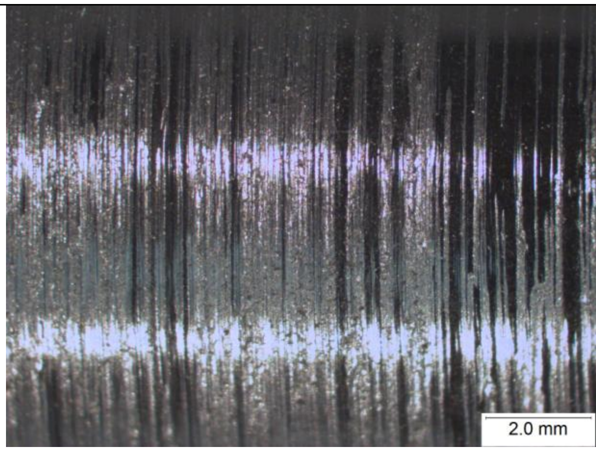
4.2 Wear Images.

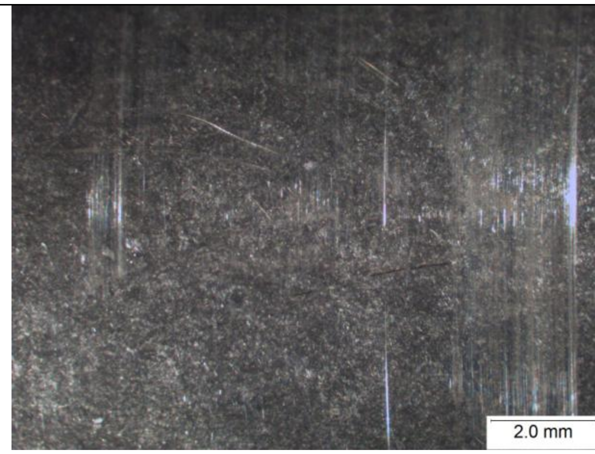
There was very little wear on the treated specimens compared with that of the non-treated specimen combinations (see Figures 5 and 6). The reduction in severe damage to both the flat specimens and the cylinder specimens is obvious. Scoring and adhesive wear dominate the non-treated specimen, while a smaller amount of abrasive wear occurs with the treated specimens.



Non-treated	Treatment 1

Figure 5. Comparison of flat specimens from two self-mated tests (VLBT 60, 61).





Non-treated	Treatment 1

Figure 6. Cylinder specimens from two self-mated tests (VLBT 60, 61).

Of the treatments examined, the best wear results were when both surfaces were treated. When only one side was treated, there was definitely an advantage over non-treated, but there was also a greater chance of transition to scuffing or localized adhesion if a small spot happens to develop an open area or pick up a fragment of debris.

4.5 Thermal Imaging Results.

A high-speed infrared camera was positioned perpendicular to the axis of the cylinder and tilted down approximately 11° in order to view the cavity formed between the cylinder and the flat plate. The emissivity of the contact cavity between a cylinder and a flat plate has an emissivity approaching one due to the multiple reflections between their surfaces. This temperature was recorded during the variable load friction test for all three conditions; both surfaces non-treated, Cylinder only treated, and both surfaces treated. Figure 7 shows a plot of the contact temperature as a function of time. Overall temperature variations during the tests were one degree or less due to the large heat-sink volume compared to the thin heat generating contact area. However, the load cycle is clearly indicated by a one degree temperature rise when both surfaces were non-treated. This load cycle is much less evident during the cylinder only treated test. In this case the variability of the contact temperature is lower and it is not clear when the load is applied. Under the test condition where both the cylinder and the flat plate are both treated with RF85 (VLBT63), the contact temperature variability is greatly reduced and the overall temperature is lower than the cases where one or both of the surfaces are untreated.

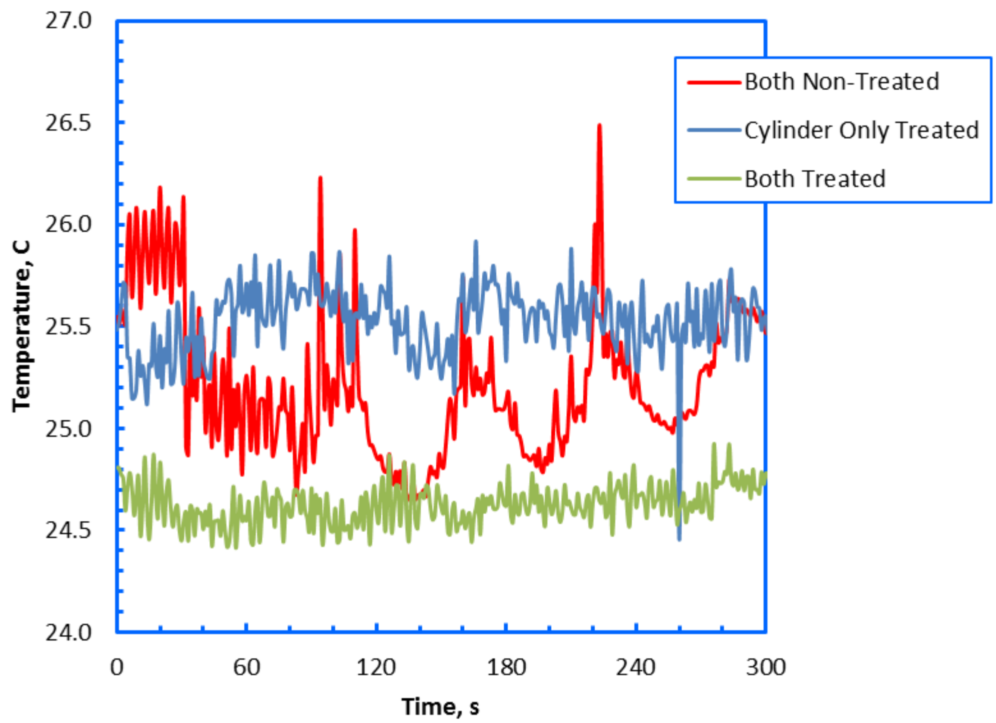


Figure 7. Comparison of Contact Temperature versus time behavior of three conditions under a variable load friction test.

5.0 Conclusions

Based on friction and wear tests of materials provided by BTN, the following conclusions were obtained.

- The BTN treatment, when applied to both sliding parts, reduced the kinetic friction coefficient of the steel couples by more than 75%.
- Treatment of both mating parts seemed to work better than treating only the cylinder specimen and not the flat specimen,
- Wear was significantly reduced by the surface treatment.
- Because only one test was conducted per condition, the repeatability of the results reported cannot be established and further testing under the conditions of the final application is recommended.
- The BTN treatment, when applied to both sliding parts, reduced the contact temperature and the contact temperature variability.

6.0 Raw Data Availability

The raw data is available in spreadsheet form for each test, as indicated by the example for test number VLBT-63 on the following page.

VLBT 63 - treatmed cyl on non-treated flat				0.1 m/s				
CYCLE 1								
Time (s)	Avg Norm F (N)	St dev Norm F (N)	Avg Fric F (N)	St dev Fric F (N)	Avg COF	St dev COF	Avg Spd (RPM)	St dev Spd (RPM)
0	0.633501	0.737687	0.231813	0.176435	0	0	0.061109	0.044435
2.012	9.335385	6.677367	1.049257	0.651855	0.112396	0.069826	0.099259	0.011898
4.013	14.831752	0.939398	1.606928	0.339863	0.108344	0.022915	0.097834	0.012033
6.015	15.074917	0.839516	1.671237	0.344655	0.110862	0.022863	0.098177	0.011863
8.016	15.074716	0.852632	1.693774	0.332244	0.112359	0.02204	0.098527	0.011473
10.016	14.861226	0.906497	1.69281	0.375649	0.113908	0.025277	0.098592	0.011729
12.015	23.297271	2.850536	2.54452	0.491745	0.10922	0.021107	0.098361	0.011675
14.016	24.587364	0.815347	2.728598	0.42266	0.110976	0.01719	0.098516	0.011701
16.014	24.57356	0.88069	2.720301	0.4395	0.1107	0.017885	0.098268	0.011667
18.015	24.571523	0.916305	2.803846	0.420078	0.11411	0.017096	0.097744	0.011798
20.013	24.484824	0.878962	2.806023	0.459284	0.114603	0.018758	0.098096	0.01192
22.014	33.296779	2.906966	3.646723	0.511467	0.109522	0.015361	0.098096	0.011404
24.015	34.483124	0.95203	3.806016	0.456621	0.110373	0.013242	0.098597	0.0117
26.016	34.391375	0.932033	3.820291	0.457427	0.111083	0.013301	0.098479	0.011521
28.015	34.492222	0.84654	3.843595	0.505543	0.111434	0.014657	0.09861	0.011653
30.014	34.315495	0.804349	3.869058	0.524729	0.11275	0.015291	0.098377	0.011734
32.016	43.0862	3.405612	4.728173	0.664431	0.109738	0.015421	0.097799	0.011548
34.015	44.553647	0.953043	4.782757	0.640829	0.107348	0.014383	0.09767	0.011966
36.016	44.467063	0.844722	4.941836	0.635467	0.111135	0.014291	0.097954	0.011679
38.015	44.514244	0.87954	4.878115	0.601231	0.109585	0.013506	0.098448	0.011583
40.013	44.487267	0.974145	4.972902	0.601318	0.111783	0.013517	0.098372	0.011663
42.015	35.161129	3.156072	4.038861	0.541935	0.114867	0.015413	0.09862	0.011494
44.017	33.857408	0.840107	4.01115	0.468962	0.118472	0.013851	0.098471	0.011868
46.015	33.850721	0.85646	3.941558	0.470454	0.116439	0.013898	0.098227	0.011617
48.016	33.869719	0.942808	4.045446	0.430946	0.119441	0.012724	0.09777	0.012007
50.015	33.91845	0.85269	4.017698	0.457436	0.118452	0.013486	0.097721	0.012062
52.015	25.245884	2.841487	3.229032	0.60219	0.127903	0.023853	0.098484	0.011544
54.015	24.048633	0.927394	3.027841	0.446396	0.125905	0.018562	0.098367	0.011745
56.015	23.973585	0.905161	3.115544	0.399897	0.129957	0.016681	0.098524	0.01173
58.016	23.997434	0.805113	3.106069	0.434793	0.129433	0.018118	0.098423	0.011782
60.015	24.046825	0.920399	3.131194	0.49966	0.130212	0.020779	0.098488	0.01158
CYCLE 5								
Time (s)	Avg Norm F (N)	St dev Norm F (N)	Avg Fric F (N)	St dev Fric F (N)	Avg COF	St dev COF	Avg Spd (RPM)	St dev Spd (RPM)
240.018	23.873083	0.879737	3.581111	0.51504	0.150006	0.021574	0.098524	0.011593
242.016	23.902958	0.881616	3.677432	0.505706	0.153848	0.021157	0.098198	0.011433
244.008	15.44335	2.862897	2.551765	0.440409	0.165234	0.028518	0.097772	0.011816
246.015	14.227213	0.863331	2.394595	0.415082	0.168311	0.029175	0.097966	0.011811
248.015	14.308775	0.833797	2.43321	0.472	0.17005	0.032987	0.098153	0.011343
250.016	14.203938	0.928695	2.361013	0.380747	0.166222	0.026806	0.098627	0.011497
252.017	14.218977	0.837393	2.421379	0.372449	0.170292	0.026194	0.098499	0.011434
254.015	23.163937	2.9774	3.516141	0.659776	0.151794	0.028483	0.098354	0.011481
256.015	24.430698	0.89168	3.773236	0.47573	0.154447	0.019473	0.098471	0.011461
258.016	24.374219	0.850139	3.689388	0.420003	0.151364	0.017231	0.097888	0.011391
260.016	24.363084	0.881776	3.73903	0.464255	0.153471	0.019056	0.097788	0.011677
262.016	24.332922	0.903976	3.710194	0.517928	0.152476	0.021285	0.097917	0.011601
264.016	32.850142	3.002666	4.849065	0.68999	0.147612	0.021004	0.098341	0.011489
266.015	34.075058	0.885818	4.992459	0.593538	0.146514	0.017419	0.098547	0.011357
268.015	34.127175	0.898788	4.952828	0.657714	0.145129	0.019272	0.098503	0.011411
270.017	33.865845	0.955232	5.01753	0.668097	0.148159	0.019728	0.098597	0.011708
272.018	34.041538	0.918802	4.916604	0.609315	0.14443	0.017899	0.098234	0.011328
274.018	43.050298	3.156485	6.072784	0.748989	0.141063	0.017398	0.097721	0.011736
276.018	44.161853	0.91436	6.103743	0.805926	0.138213	0.018249	0.097635	0.011756
278.017	44.446917	0.908662	6.163128	0.7527	0.138663	0.016935	0.098092	0.011451
280.017	44.406681	0.826196	6.178795	0.743406	0.139141	0.016741	0.098321	0.011584
282.016	44.394829	0.927182	6.173763	0.678866	0.139065	0.015292	0.098407	0.011543
284.018	34.957914	3.088344	5.027808	0.752421	0.143825	0.021524	0.098617	0.011611
286.017	33.780466	0.905725	4.940533	0.666709	0.146254	0.019737	0.098375	0.0116
288.017	33.611804	0.890172	4.903668	0.570418	0.145891	0.016971	0.097875	0.011696
290.018	33.683695	0.878289	5.037069	0.694226	0.14954	0.02061	0.097756	0.011924
292.017	33.719023	0.923818	5.026844	0.622302	0.14908	0.018456	0.098074	0.011583
294.017	25.009034	3.034307	3.71494	0.577815	0.148544	0.023104	0.098571	0.011545
296.017	24.005183	0.912568	3.633786	0.394958	0.151375	0.016453	0.098593	0.011535
298.018	24.024153	0.939133	3.575847	0.463708	0.148844	0.019302	0.098319	0.011629
300.017	23.854802	0.915923	3.639157	0.442024	0.152554	0.01853	0.098602	0.011658