Guidance - Friction Noise Signal

Background

Surface damage can give rise to a disorderly instantaneous friction signal which can be analysed and quantified through post-processing the instantaneous (high-speed) friction signal. In the absence of high-speed data, an analogue measure of "friction noise" can provide useful data.

Signal Conditioning

The standard (low data rate) r.m.s. friction signal is generated by passing the input voltage through a true r.m.s. to d.c. converter. This produces a time smoothed r.m.s. value of the friction force, integrated over a period of just over 1 second. Because the friction force signal approximates to a square wave, the r.m.s. friction signal can be considered as an average friction force as measured over at least one complete cycle, assuming a reciprocating frequency greater than 1 Hz.

By rectifying the instantaneous friction force signal and subtracting the r.m.s. average, a resulting signal corresponding to the perturbations ("friction noise") can be produced. If this signal is subsequently passed through a second true r.m.s. to d.c. converter, an r.m.s. signal of "friction noise" can be generated. This can be used, in real time, as an analogue measure of the "friction noise", hence the orderliness or otherwise of the friction signal. By dividing the r.m.s. "friction noise" value by the r.m.s. friction signal value, a percentage "friction noise" value (as a derived channel in software) can be generated.

Example 1 – Base oil versus base oil plus ZDDP

These tests were run using a hard ball on a soft steel flat, as this arrangement is known to be susceptible to producing surface damage and hence disorderly friction.

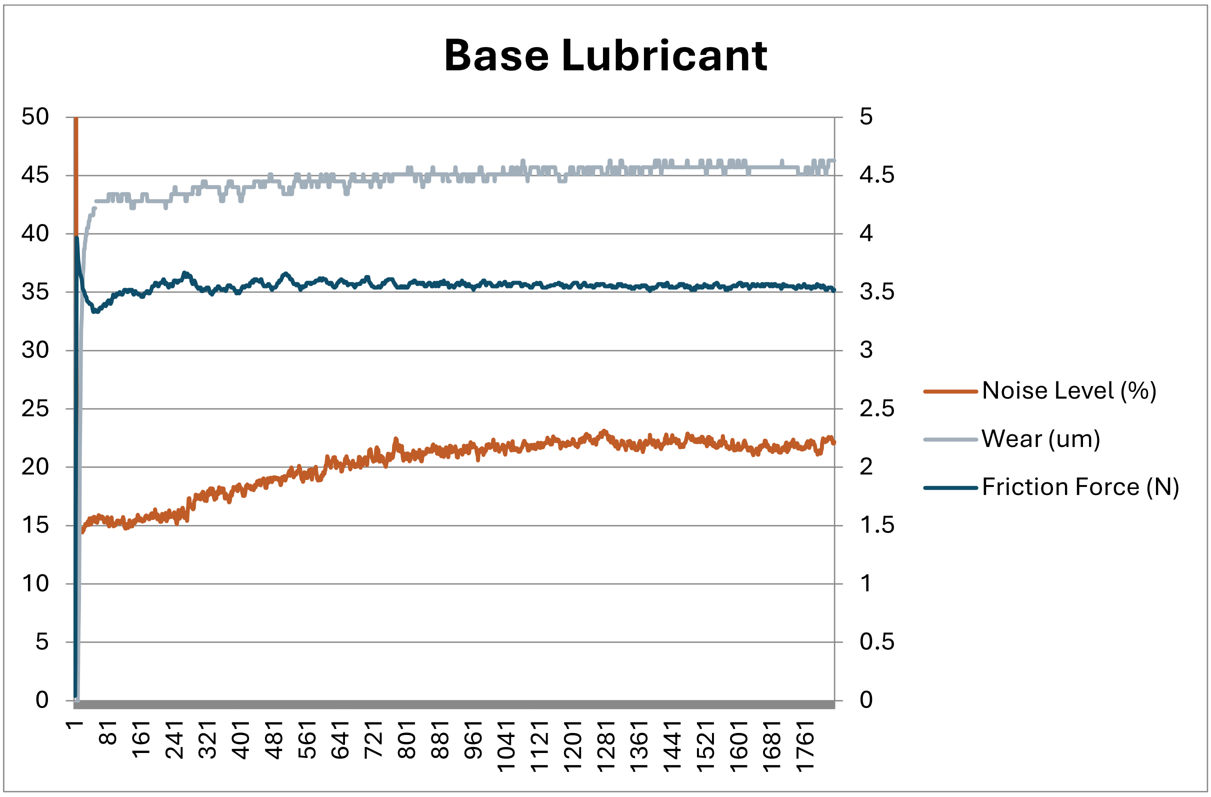


Figure 1: Test with Base Oil

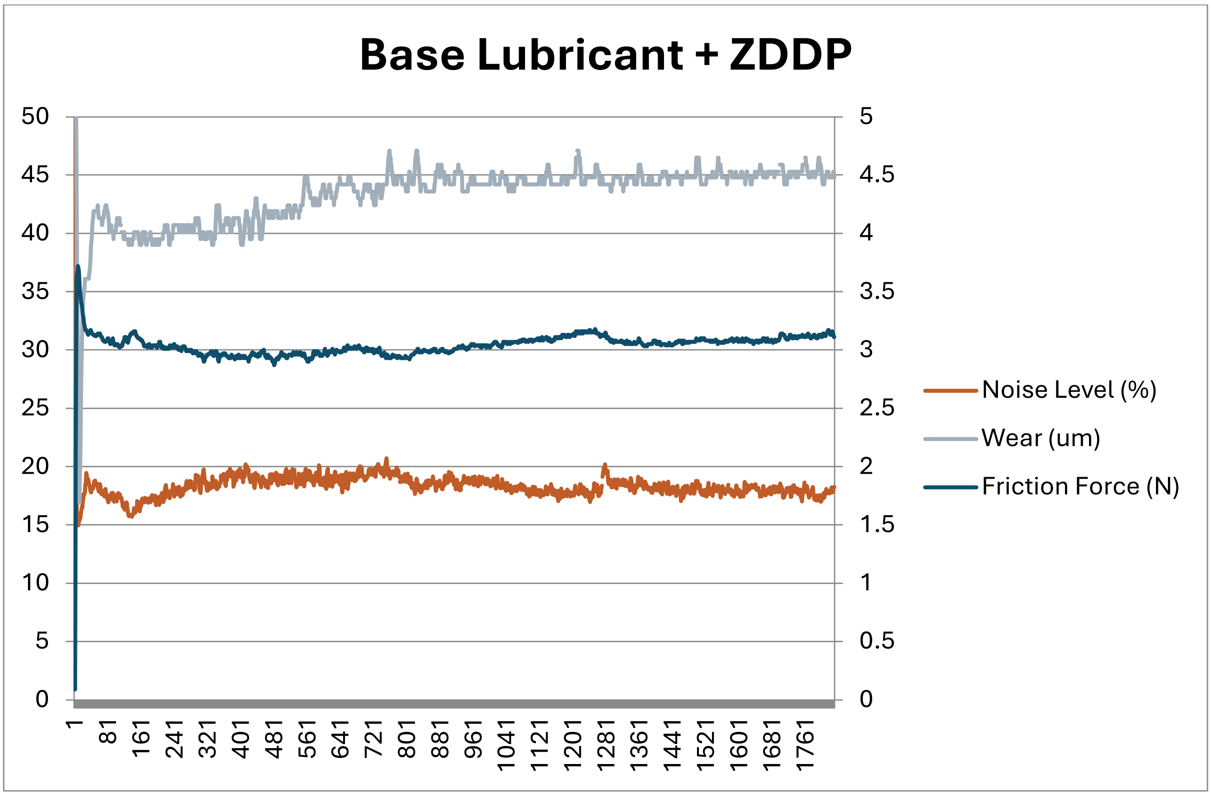


Figure 2: Test with Base Oil + ZDDP

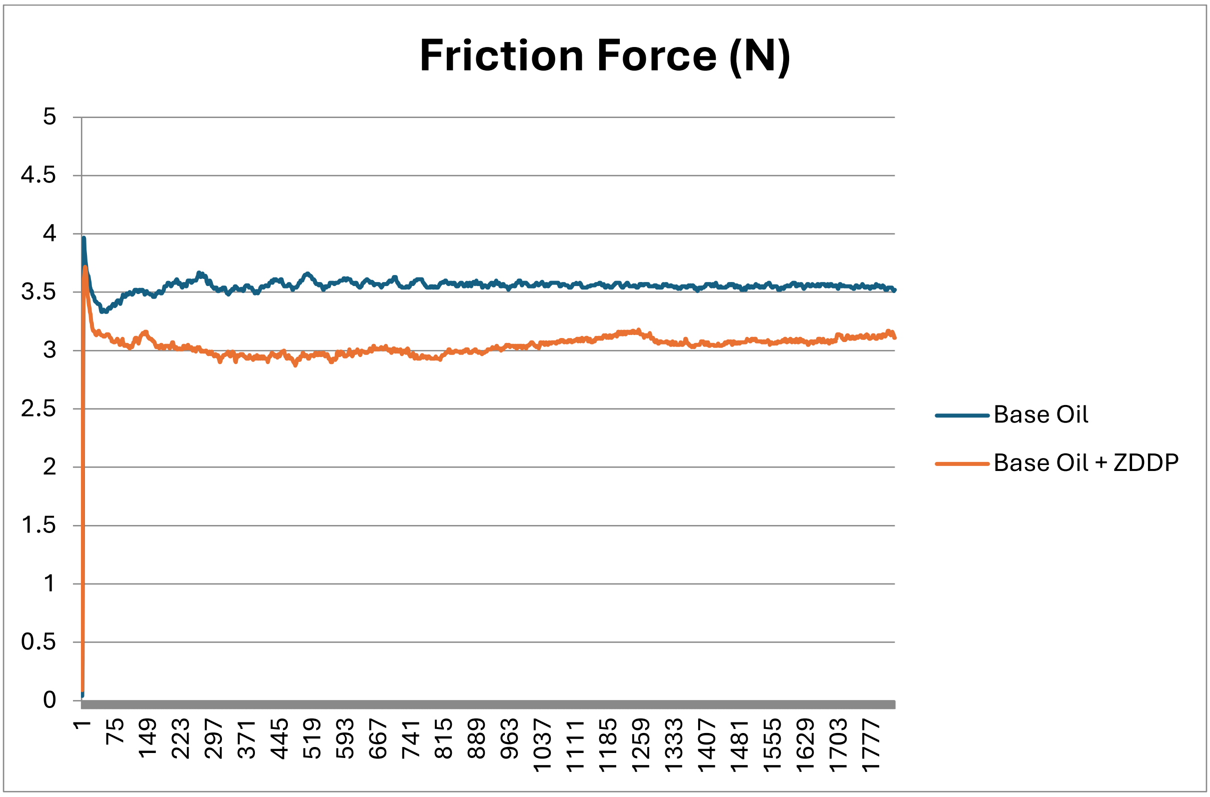


Figure 3: r.m.s. friction force

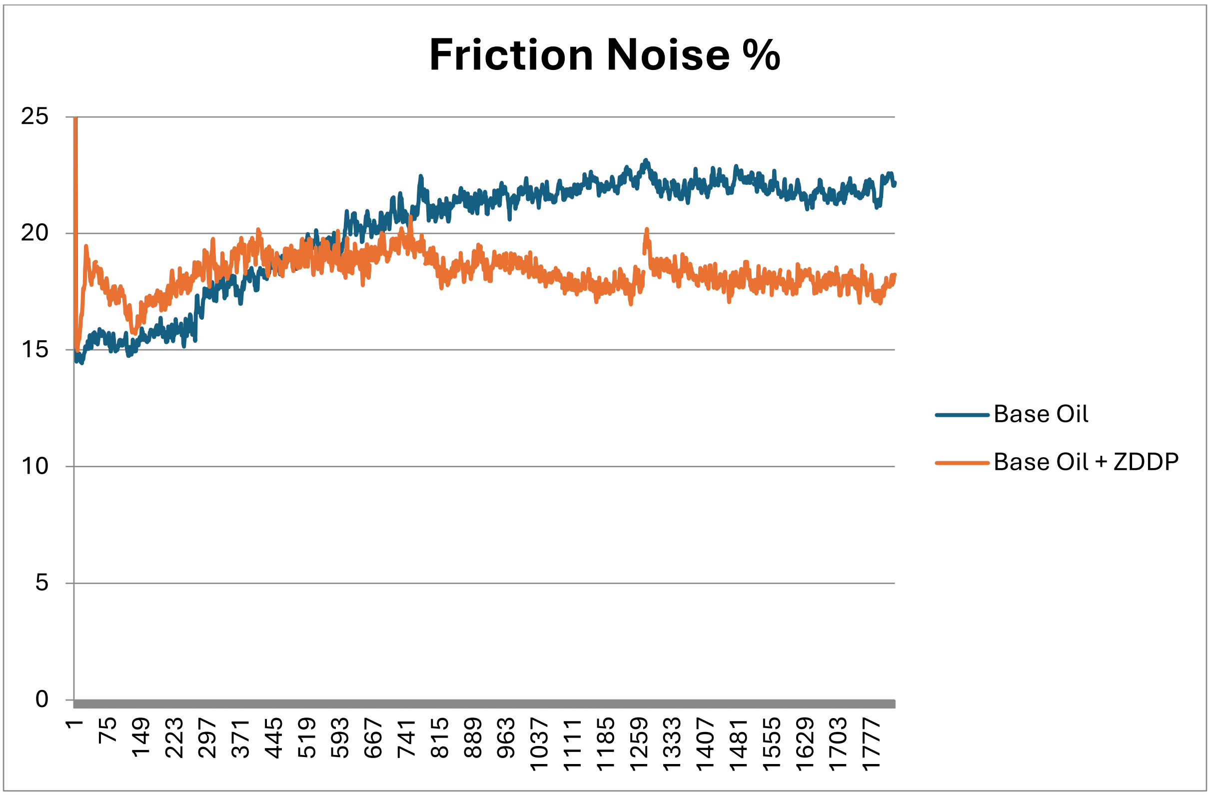


Figure 4: Friction noise percentage

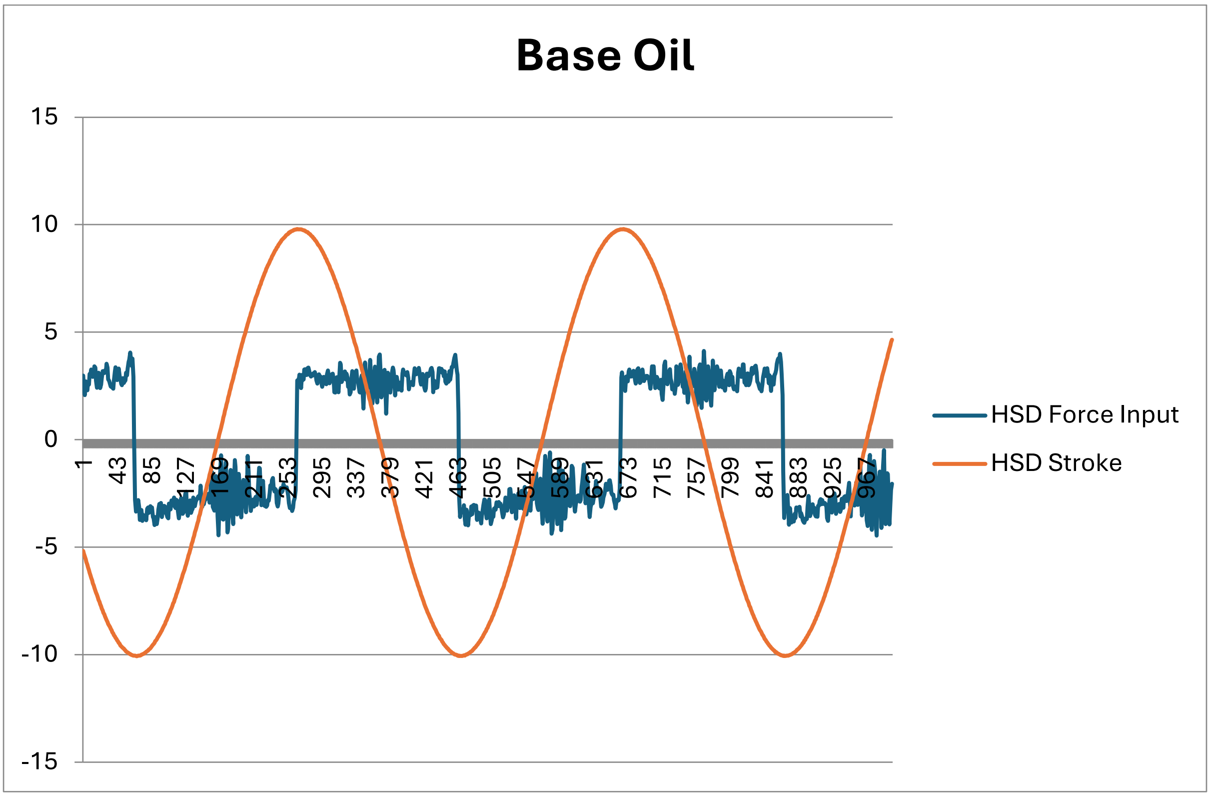


Figure 5: Instantaneous friction force – test end

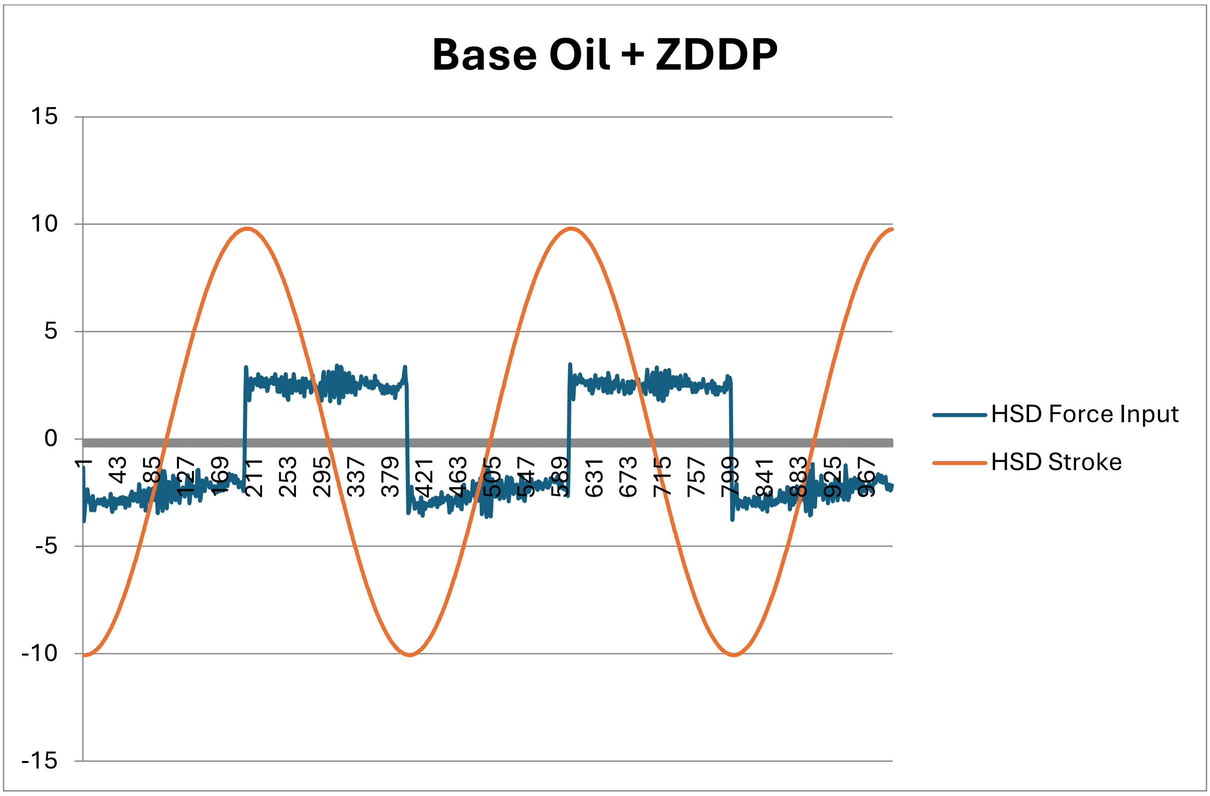
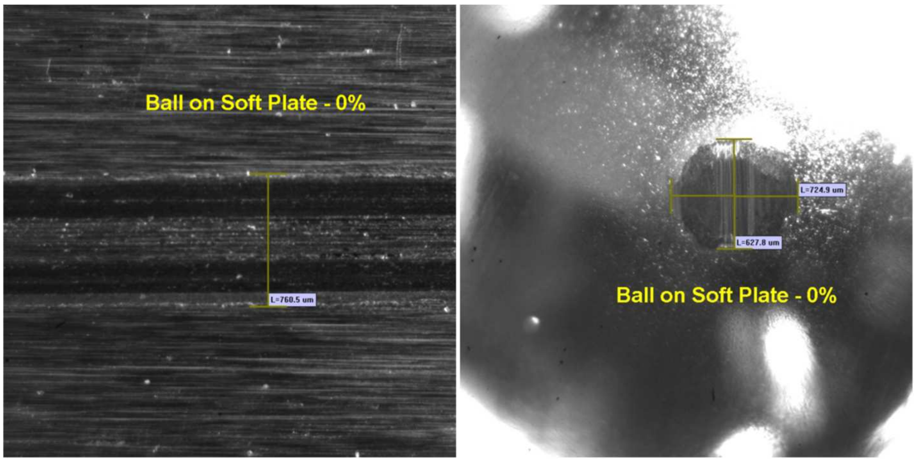


Figure 6: Instantaneous friction force – test end

The friction noise signal indicates that the instantaneous friction signal for the base oil is more disorderly than the friction signal for the base oil plus ZDDP. Examination of the high-speed data friction signals indicates a more prominent mid-stroke perturbation to the base oil friction signal.

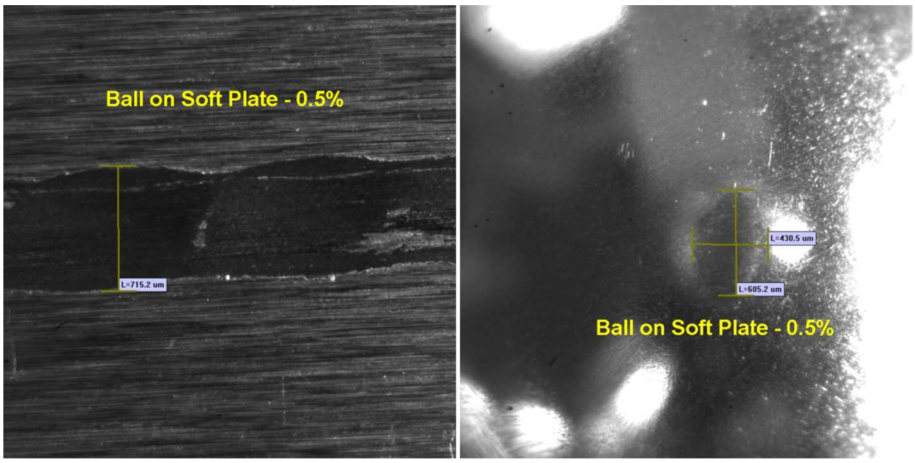
Example 2 – PAO versus PAO plus 0.5% OFM

These tests were run using a hard ball on a soft steel flat, as this arrangement is known to be susceptible to producing surface damage and hence disorderly friction.



761 725 x 628

Figure 1: Ball on Soft Plate - PAO



715 431 x 605

Figure 2: Ball on Soft Plate – PAO + 0.5% OFM

Without the added friction modifier, the wear scar is similar to that produced with the low lubricity reference fluid in the ISO diesel fuel lubricity test. The addition of a friction modifier reduces the size of the ball wear scar, resulting in an elliptical scar similar to that produced by the high lubricity reference fluid. Curiously, the corresponding plate wear scar, although smaller, appears to have wavy edges.

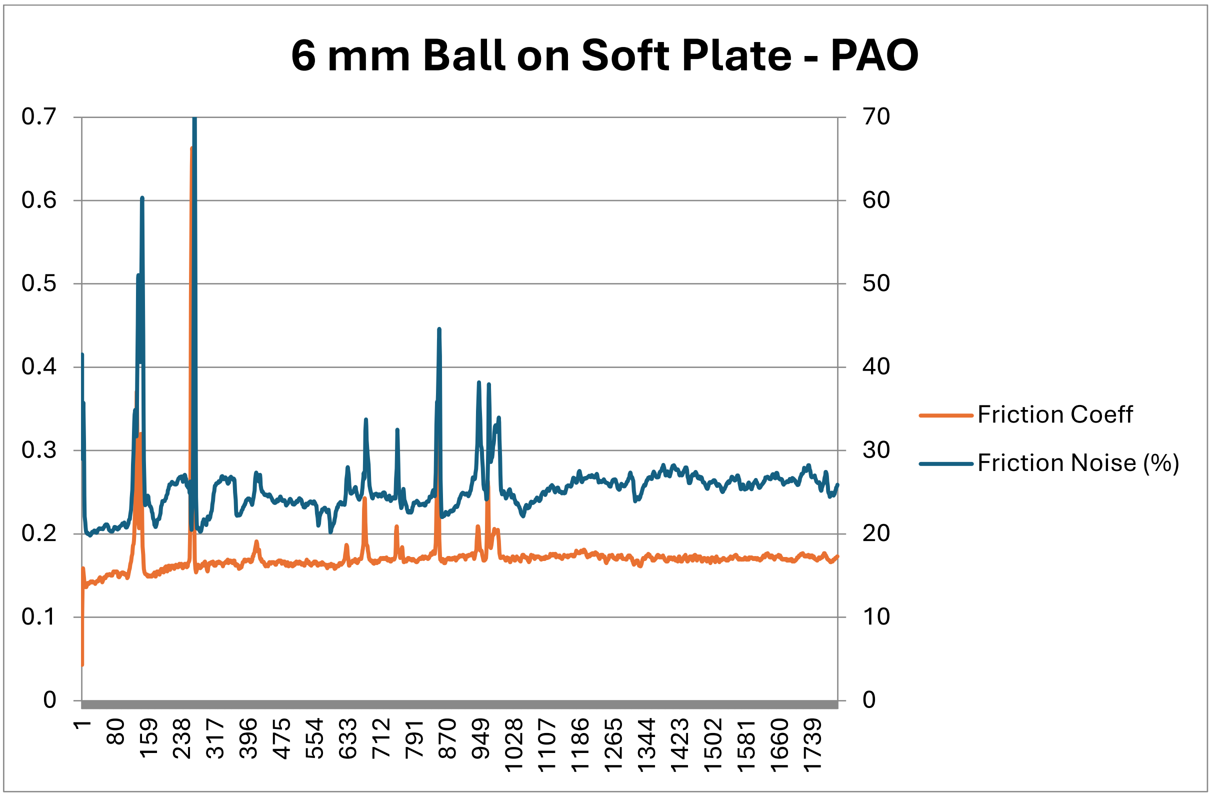


Figure 3: Soft Plate - PAO

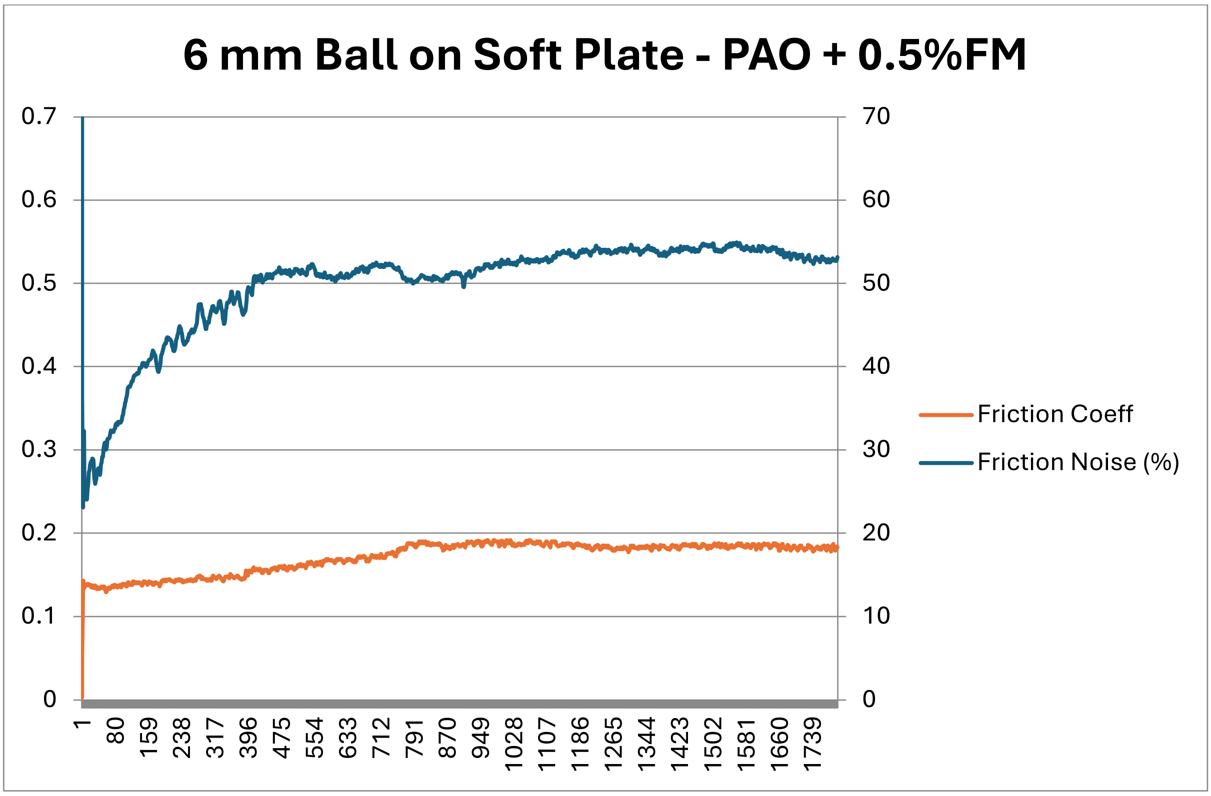


Figure 4: Soft Plate – PAO + 0.5% OFM

Comparison of Instantaneous Friction – Soft Plate

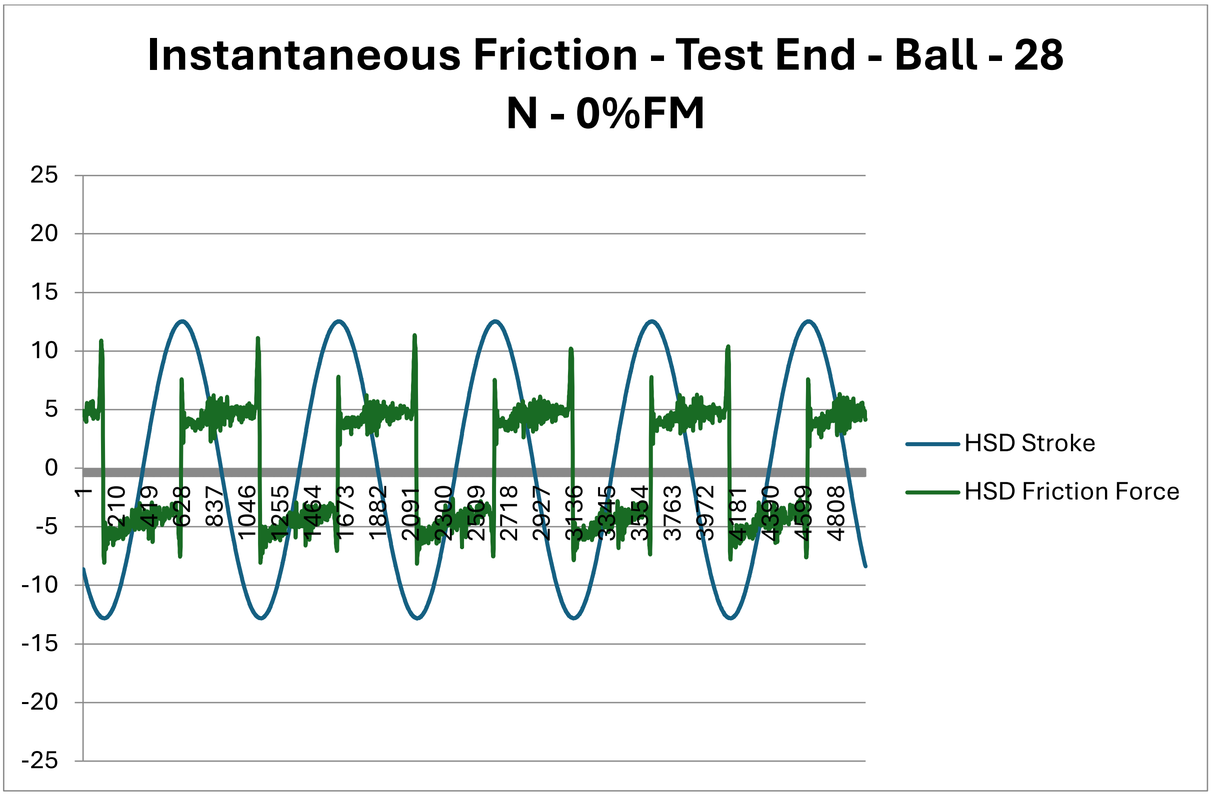


Figure 5: Soft Plate - PAO

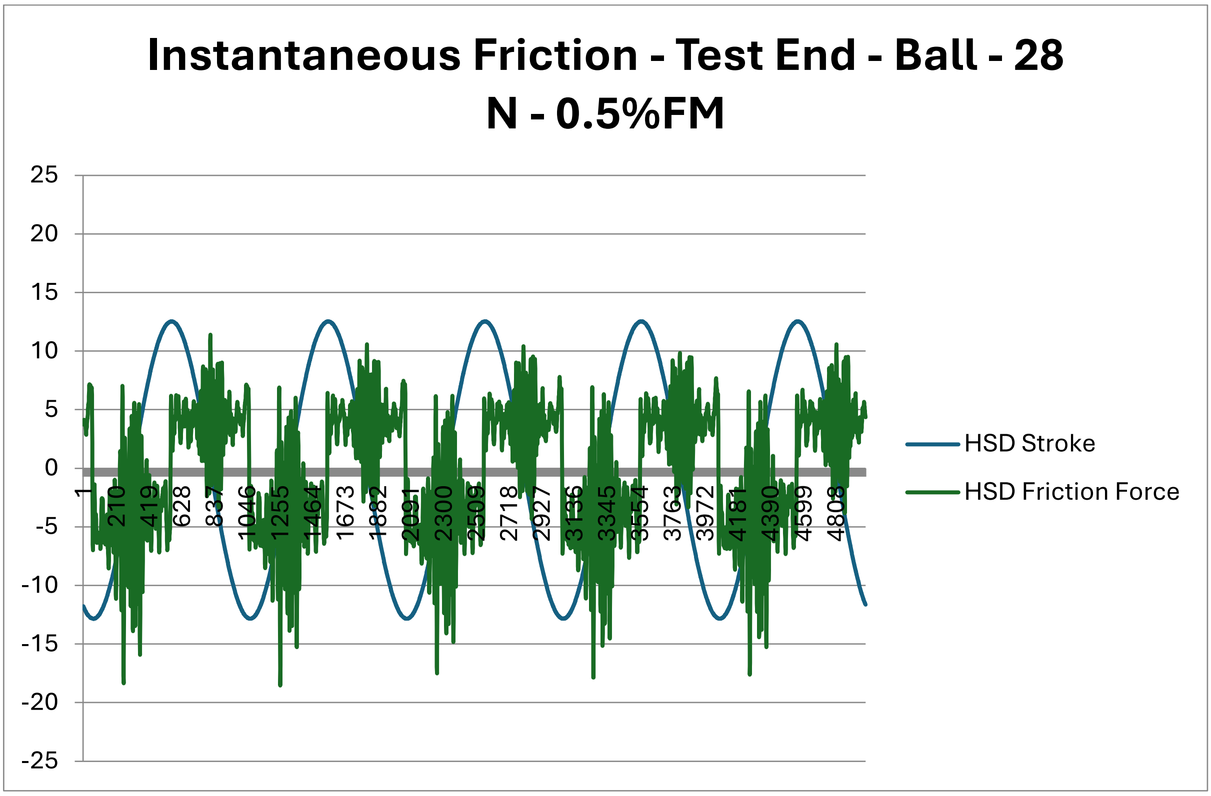


Figure 6: Soft Plate – PAO + 0.5% OFM

The test with the PAO base fluid produced a number of spikes in both the r.m.s. friction and the friction noise traces, indicating scuffing type events. These were not observed with the test with 0.5% OFM added, however, in this case, the friction noise level was much higher, indicating a more disorderly friction signal, caused by something other than scuffing.

Examination of the instantaneous friction traces shows that with the OFM test there is a major disturbance to the instantaneous friction trace about the mid-stroke position and this accounts for the high level of friction noise signal recorded.

Further examination of the plate specimens provides an explanation for this behaviour. Both with and without OFM, the plate wear scars have been subjected to a degree of plastic flow (ratchetting), but this is more severe and more pronounced in the test with the OFM added.

Figure 7: Soft Plate - PAO

Figure 8: Soft Plate – PAO + 0.5% OFM

The addition of OFM appears to reduce adhesion allowing more severe plastic deformation. It is worth noting that a similar result can be generated with the same fluids and plates, with a line contact configuration:

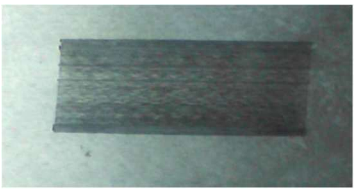


Figure 9: **Soft Plate – PAO - Wear**

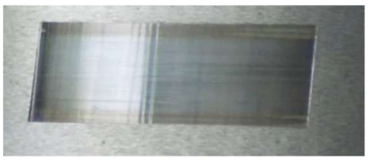
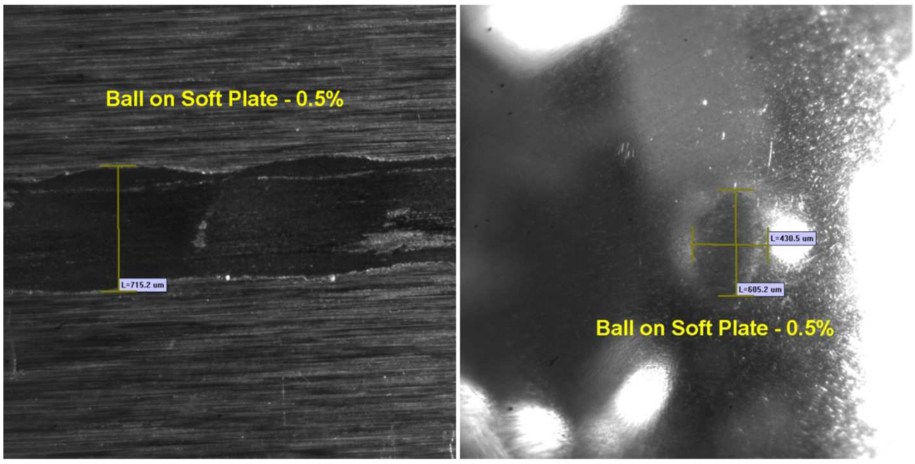


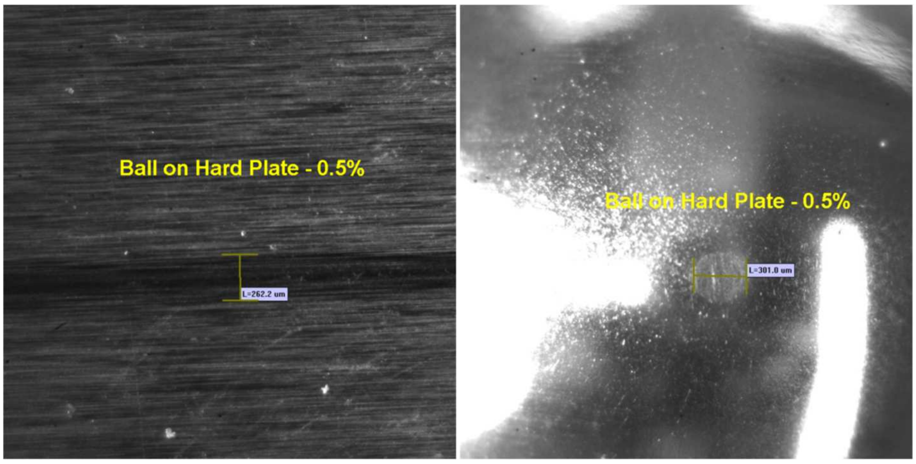
Figure 10: Soft Plate – PAO + 0.5% OFM – Plastic Flow

Comparison – Soft and Hard Plates – PAO + 0.5% OFM



715 | 431 x 605

Figure 11: Ball on Soft Plate – PAO + 0.5% OFM



262 | 301 x 301

Figure 12: Ball on Hard Plate – PAO + 0.5% OFM

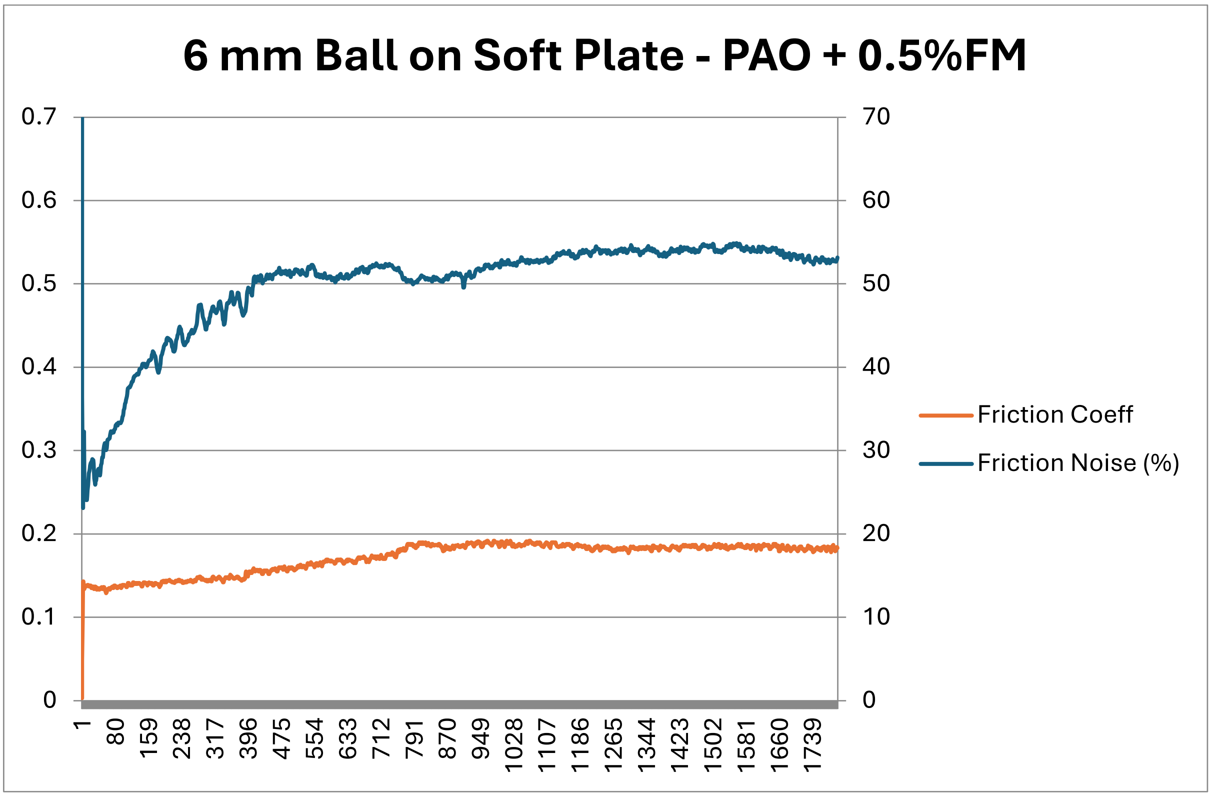


Figure 13: Ball on Soft Plate – PAO + 0.5% OFM

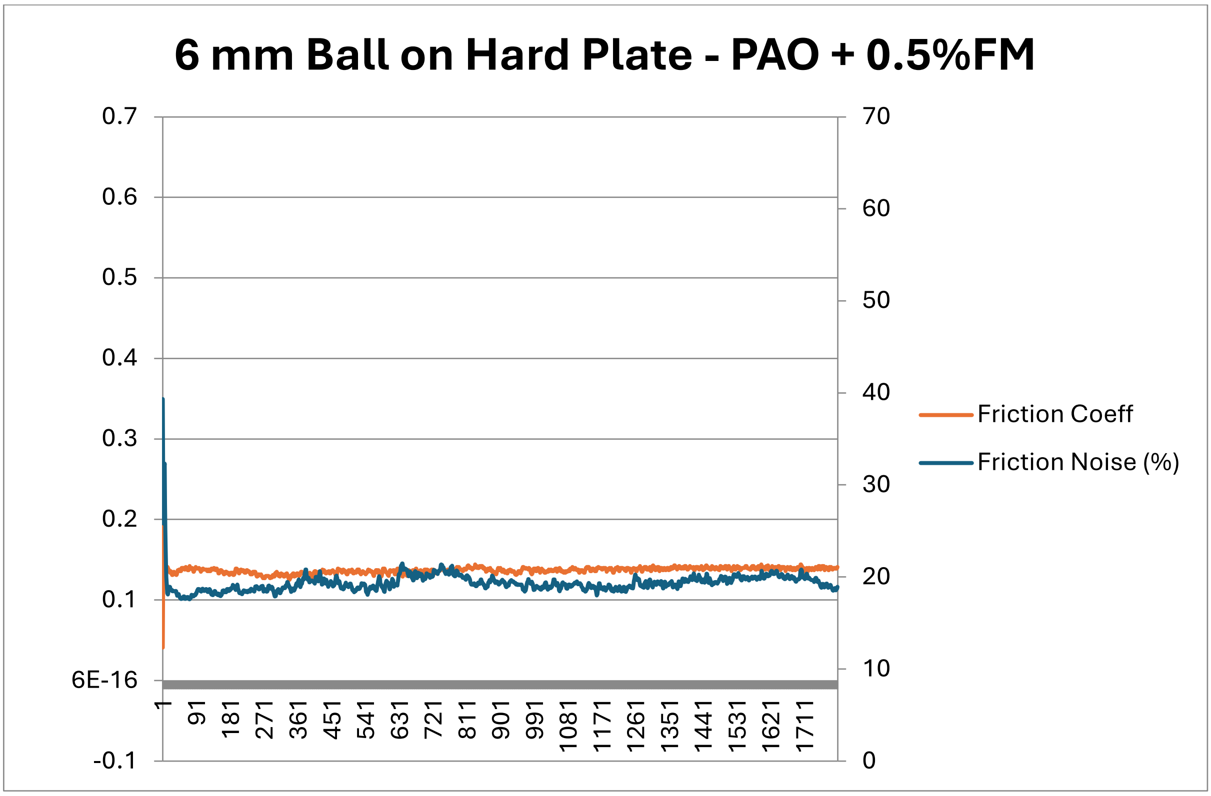
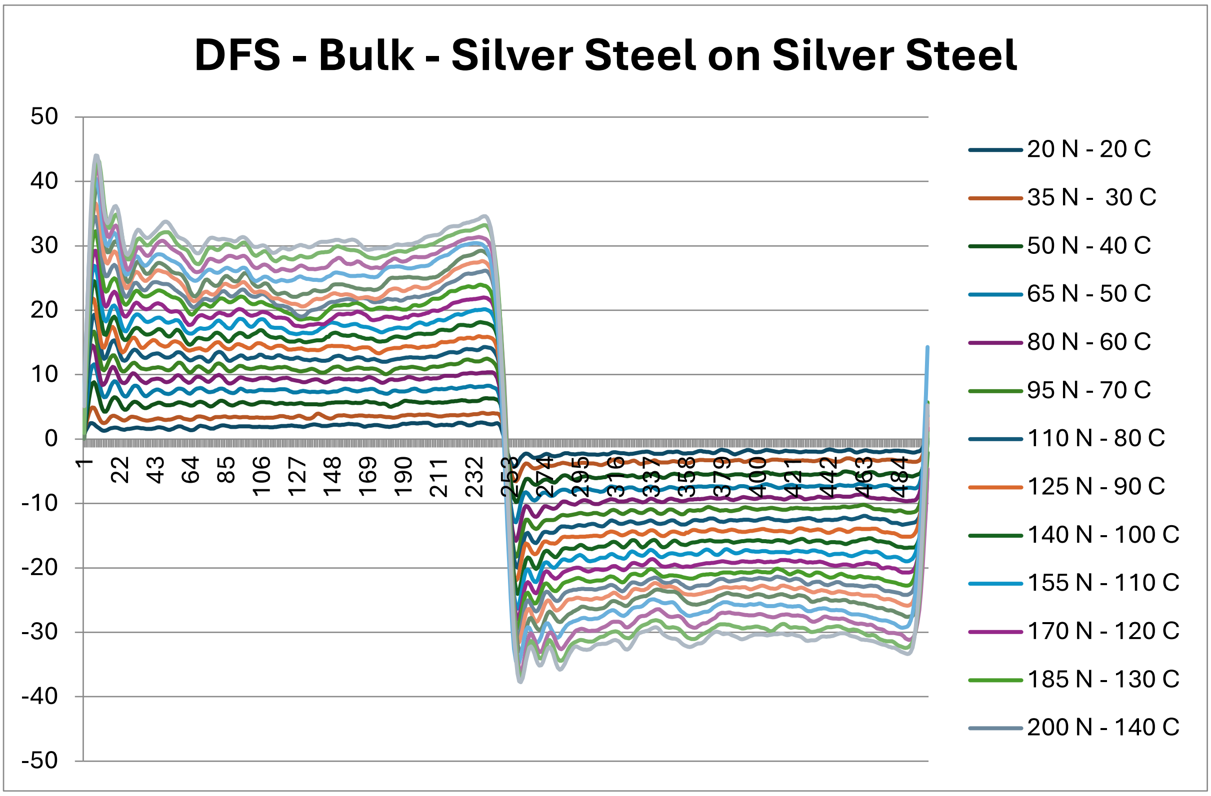


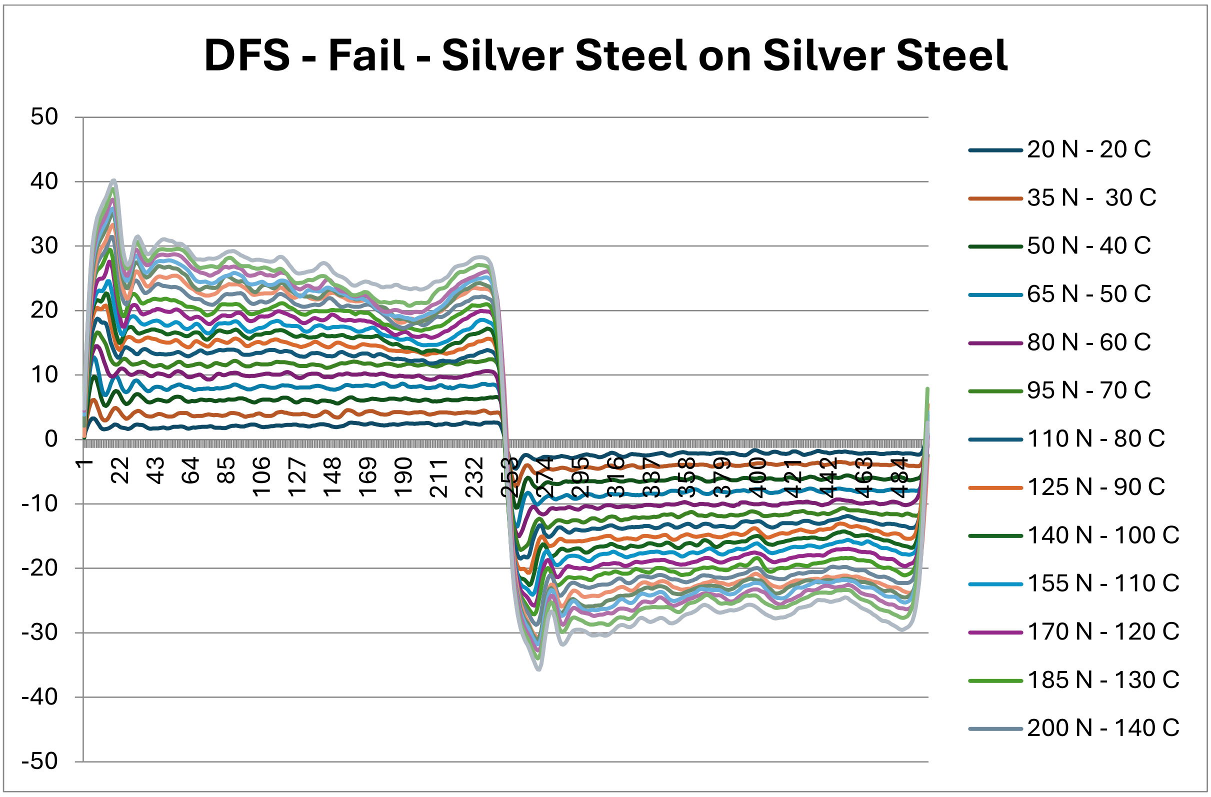
Figure 14: Ball on Soft Plate – PAO + 0.5% OFM

Comments on Soft versus Hard Plate Tests

Running on a hard plate eliminates the plastic flow associated with running on a soft plate, with a resulting reduction in both friction coefficient and friction noise.

High Speed Friction

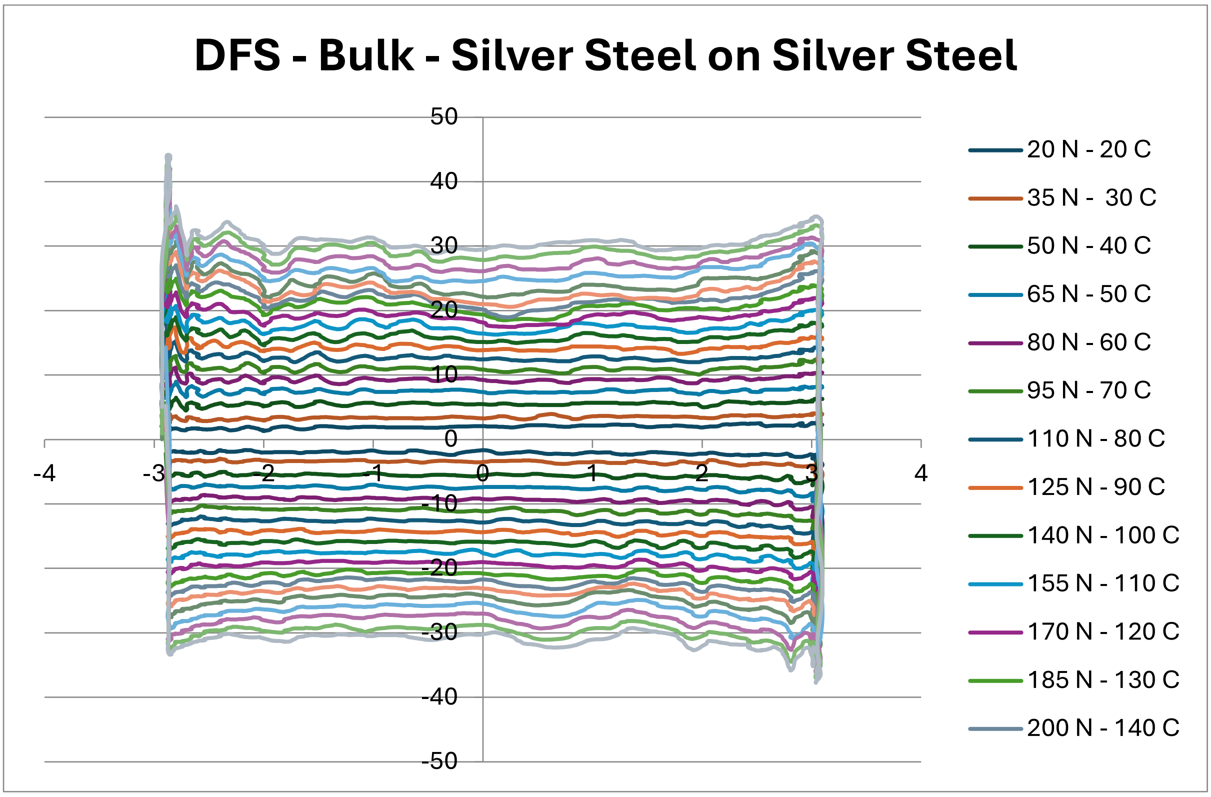


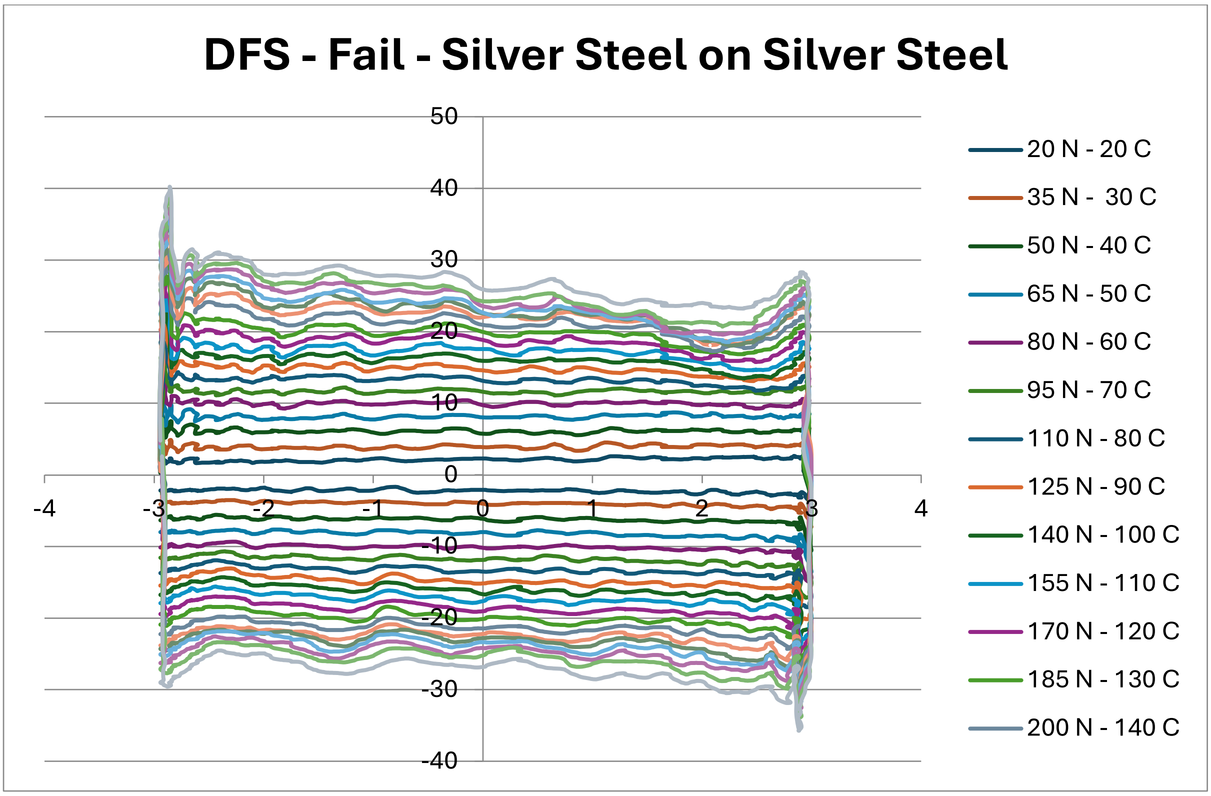


The high-speed friction traces show a difference in response between the BULK and the FAIL samples. At the higher loads, there is a significant dip in friction at the end of each stroke.

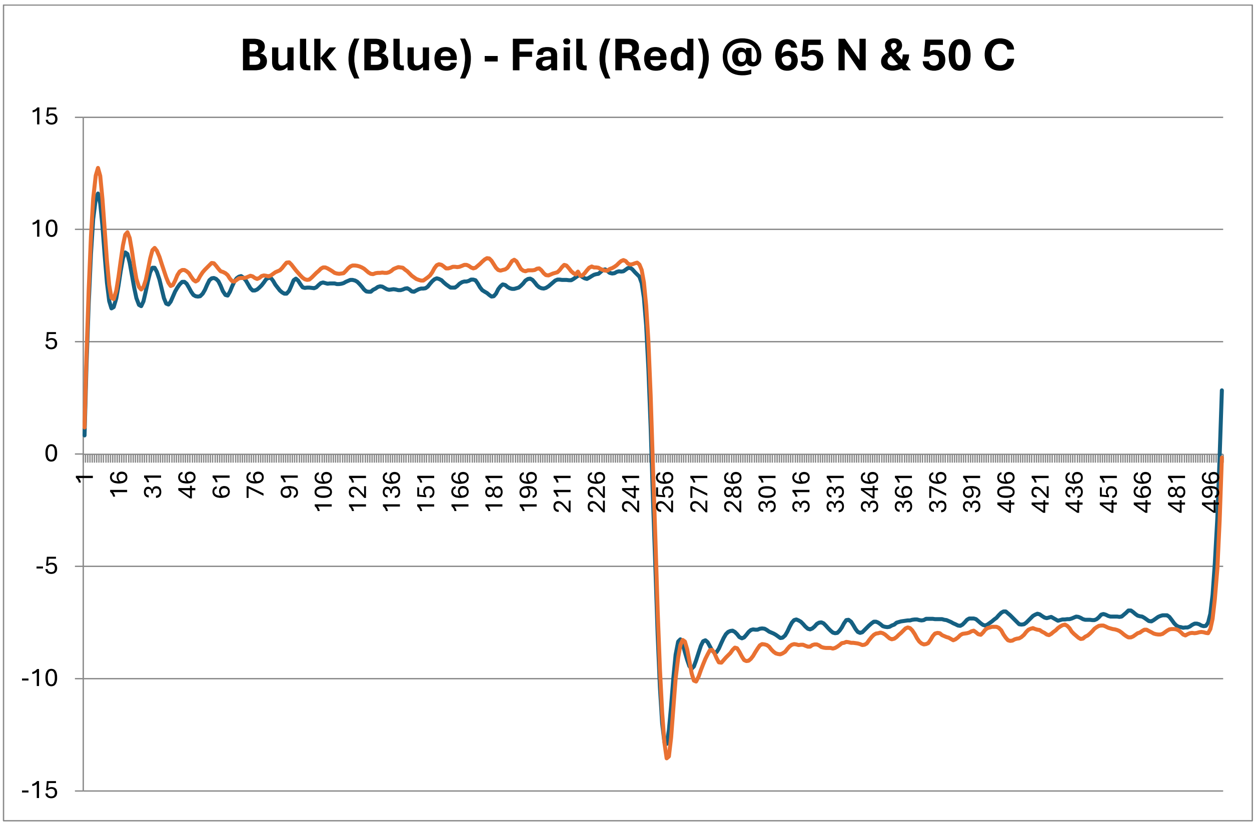
This perhaps coincides with the obvious polished patches at the stroke ends, giving rise to an increase in adhesive friction at the beginning of the stroke and a reduction in friction at the end of the stroke. This kind of behaviour has been observed before.

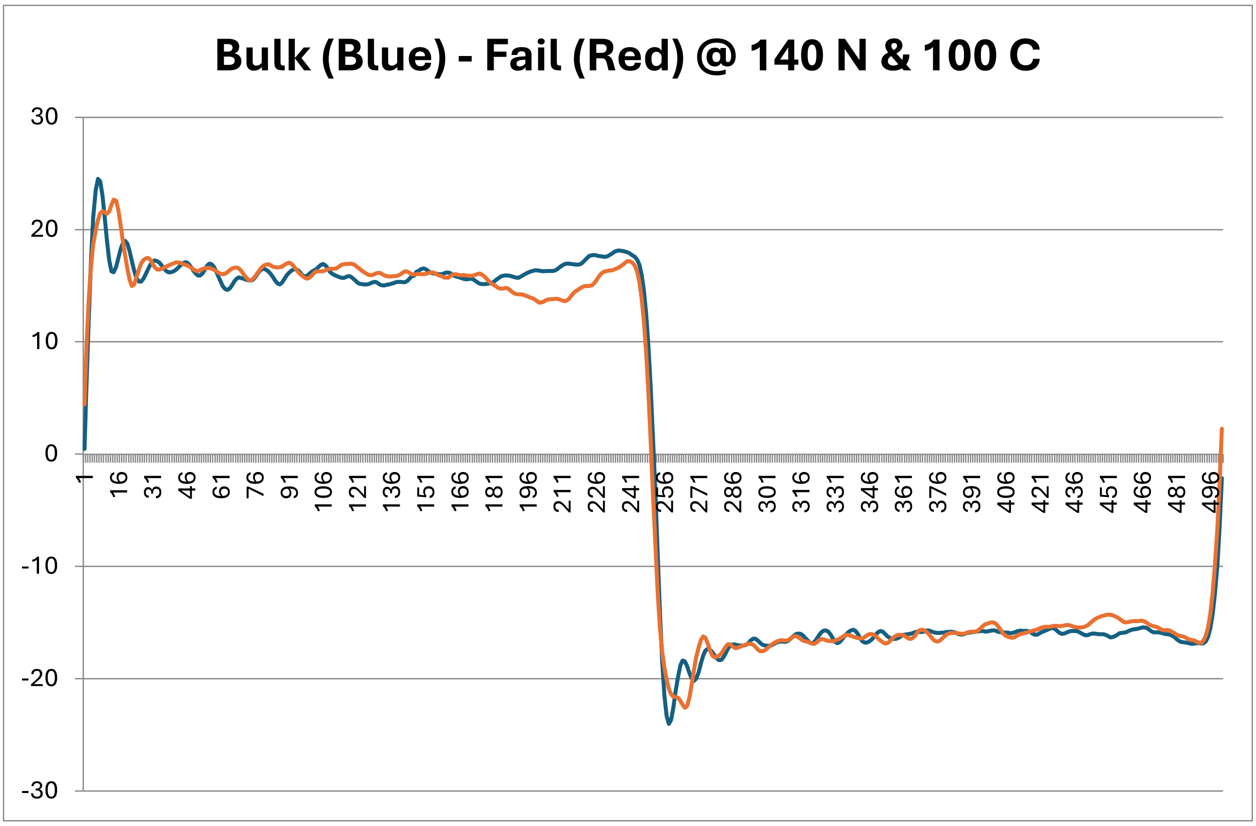
By contrast, the BULK sample produces a much shorter friction peak at the beginning of the stroke and more uniform friction for the remainder of the stroke, consistent with the more uniform but less severe adhesive wear observed on the specimens.





Comparative instantaneous friction traces at selected Load/Temperature set-points are as follows:


Bulk (Blue) - Fail (Red) @ 65 N & 50 C
15
10
5
0
-5
-10
-15
1
16
31
46
61
76
91
106
121
136
151
166
181
196
211
226
241
256
271
286
301
316
331
346
361
376
391
406
421
436
451
466
481
496


Bulk (Blue) - Fail (Red) @ 140 N & 100 C
30
20
10
0
-10
-20
-30
1
16
31
46
61
76
91
106
121
136
151
166
181
196
211
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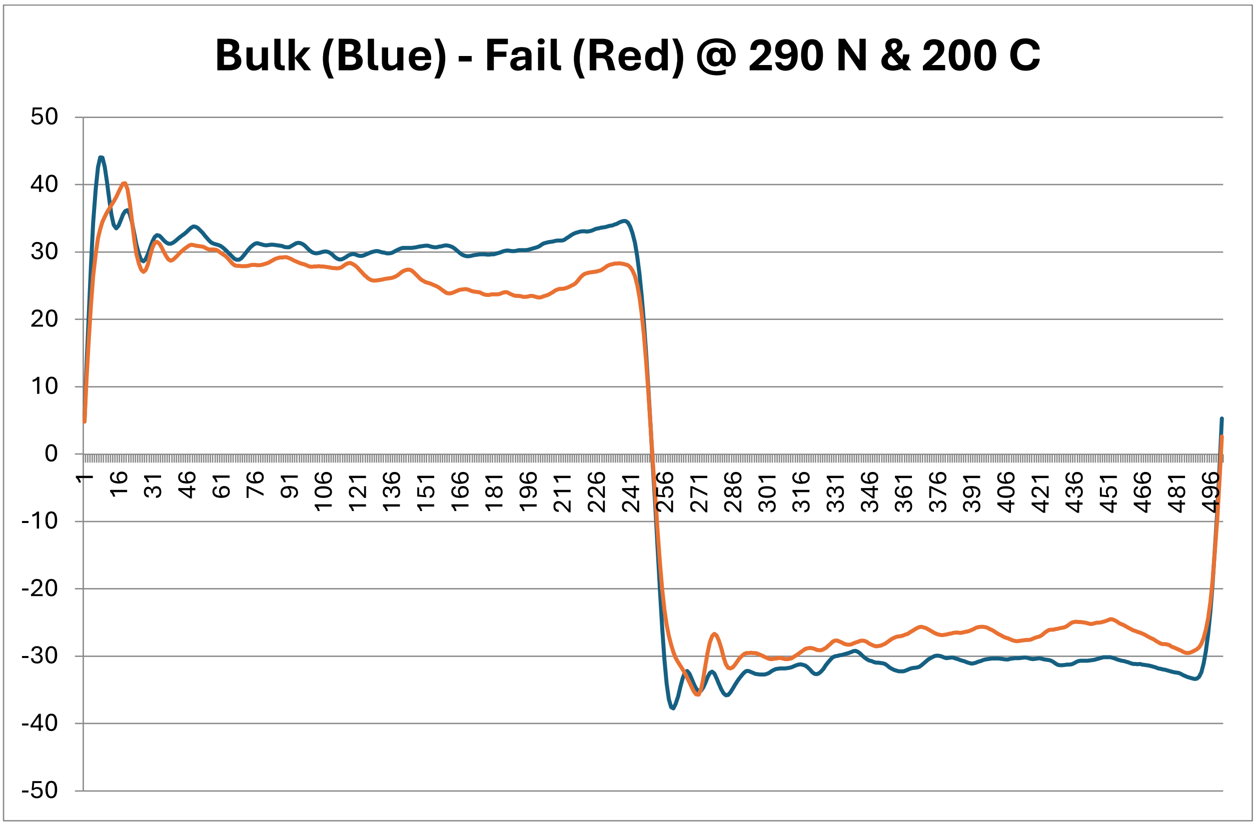
436
451
466
481
496



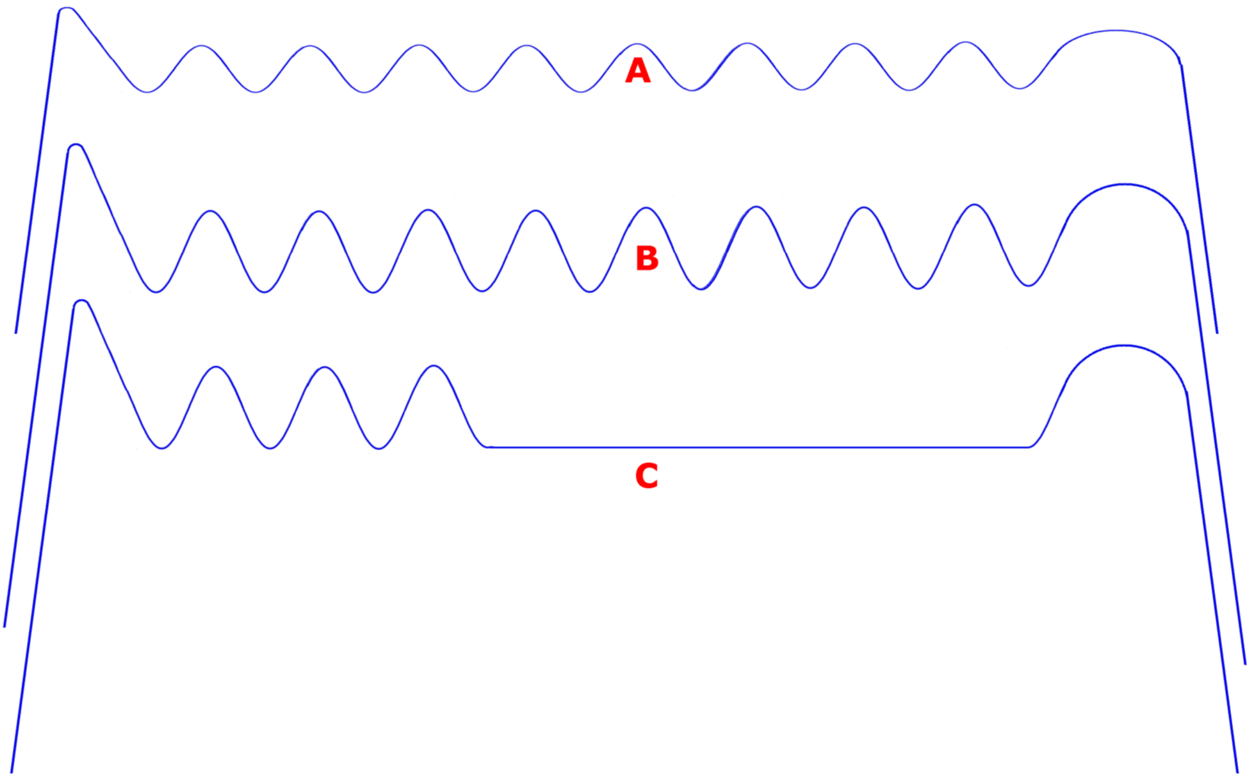
The following observations are made with regard to the FAIL traces:

- The magnitude of initial friction spike reduces but the position of the peak is delayed
- When sliding at decreasing velocity towards the smoother surface at the end of the stroke, the friction decreases
- When starting from rest and initially accelerating across the smoother surface, the friction spikes

Instantaneous friction is clearly dependent on local topography and motion, whether starting from rest, or coming to rest. We have observed this kind of response elsewhere.

Friction Noise Signal

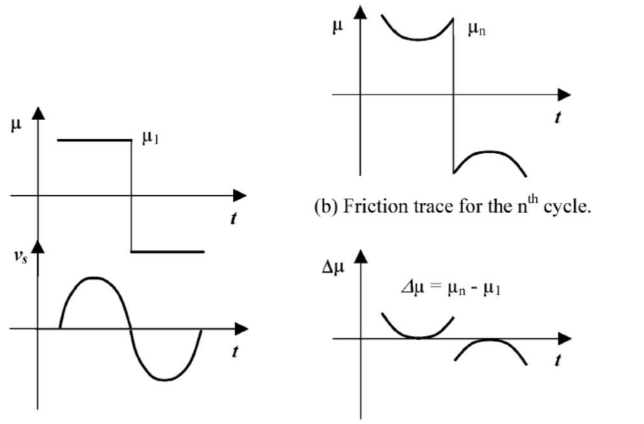
The friction noise signal is useful in certain circumstances, but there are situations where it is not effective, this being one of them. Considering the following examples, if the instantaneous friction signal becomes fairly uniformly more rough, say progressing from A to B, the friction noise signal will increase. If, however, the instantaneous friction becomes rougher over part of the stroke, and smoother elsewhere, the friction noise, progressing from A to C, may not change or may indeed reduce.



Oakridge Scuffing Detect Method

Blau et al suggested that scuffing in their fuel lubricity tests started at stroke beginning and developed progressively towards the middle of the stroke, accompanied by a change in shape of the instantaneous friction.

Their technique involved recording the instantaneous friction on the first cycle of their test, then subtracting this from subsequent instantaneous cycles. This has similarities to the friction noise approach, but it is not clear what happens if, say, the initial stroke produces rougher friction than subsequent strokes. There are of course other limitations, which perhaps limit the usefulness of this technique.



(a) Friction trace and sliding velocity for the 1st cycle.

(c) The change of friction coefficient for the nth cycle compared to the 1st cycle.

Fig. 4. A schematic drawing of the friction traces at individual stroke cycles.

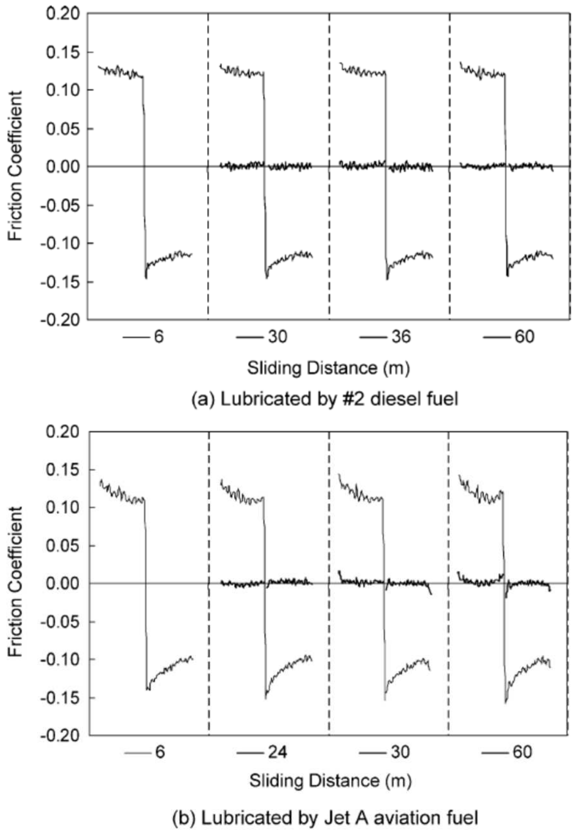


Fig. 8. Friction coefficient traces of zirconia against 52100 steel.

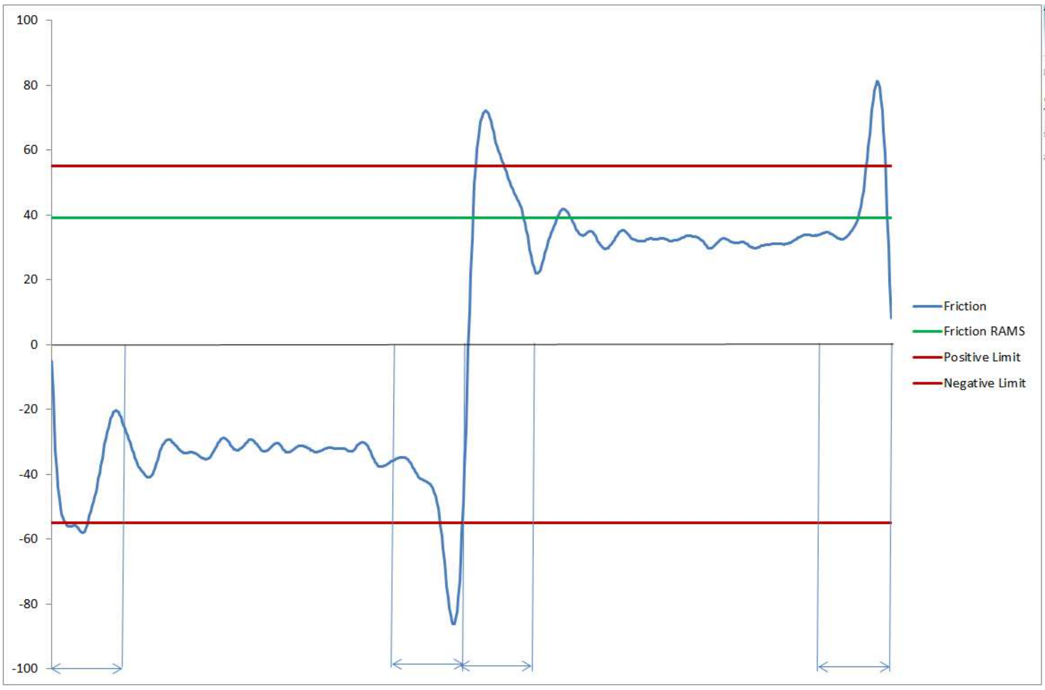
Investigation of the scuffing characteristics of candidate materials for heavy duty diesel fuel injectors

Jun Qu, JJ Truhan, PJ Blau

Tribology International 38 (2005) 381-390

Kamps Scuffing Algorithm

With this, the user sets two upper and lower limits in percentage of RMS friction, plus a time limit as a percentage of the reciprocating period.



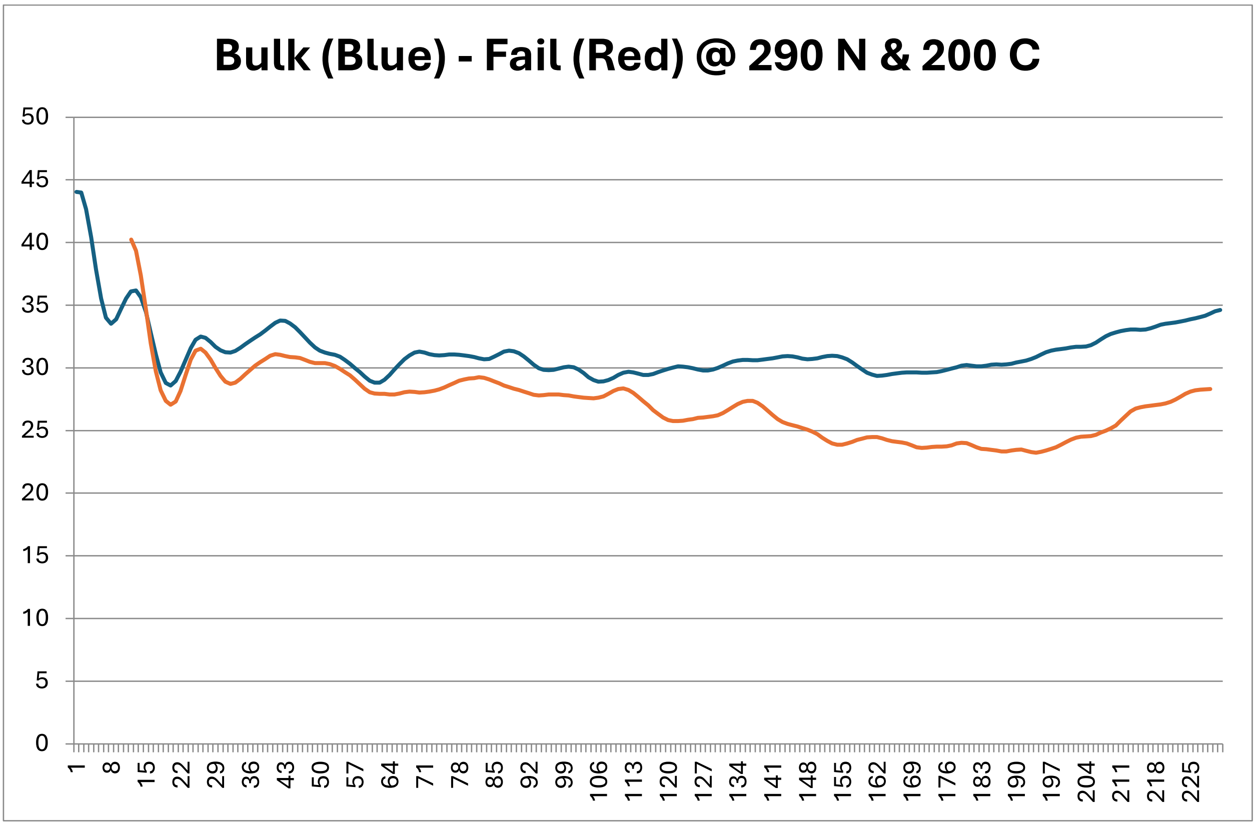
If, during the set time limit, the friction of the first negative peak and the friction of first positive peak exceed the limits set, then “first” scuff is detected. In the same way if the friction signal of the second negative peak and the friction signal of the second positive peak exceed the limits then “second” scuff is determined.

This approach does at least recognise that different regimes may exist at different stroke positions and allows the focus to be directed to areas where scuffing is likely to occur. The weakness of the method is that it requires the user to set the limits and it is not clear whether this can be done by anything other than a fairly arbitrary rule of thumb.

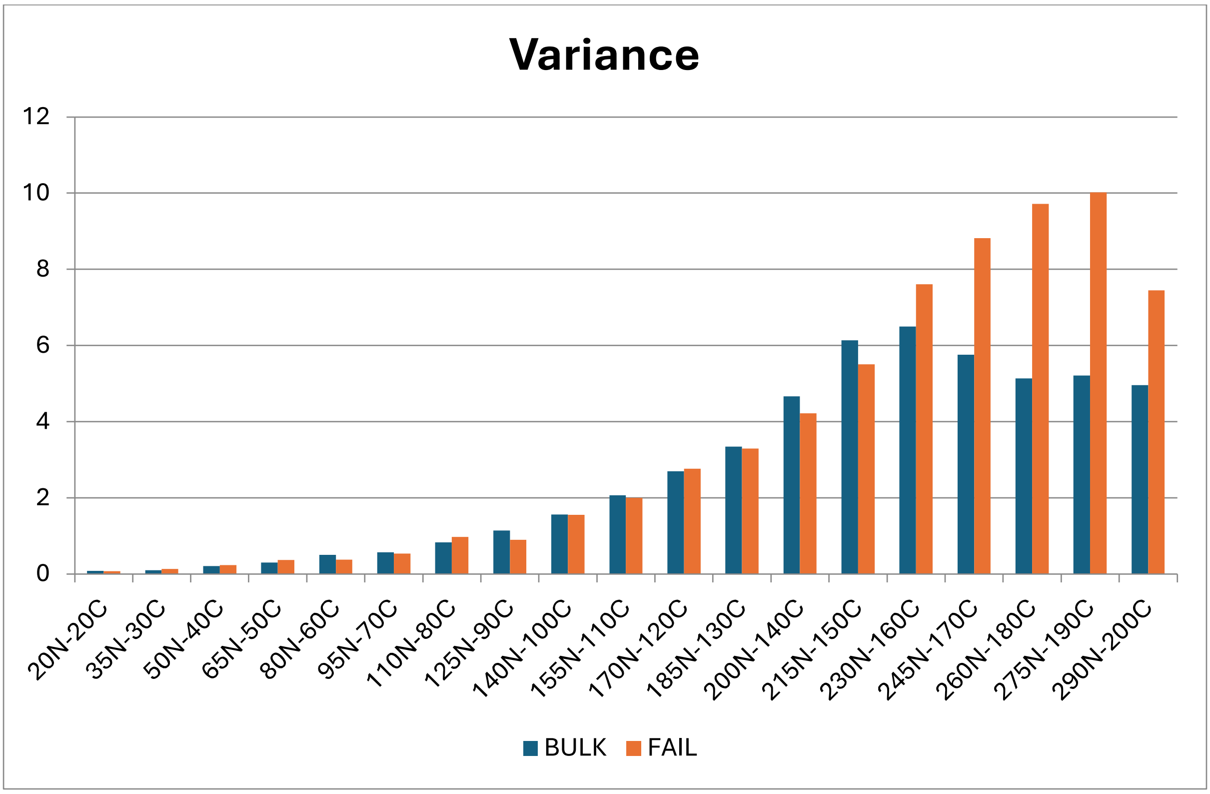
New Variance Method

It is apparent that with running-in and wear, the mean friction coefficient may indeed decrease, not increase, and the friction become locally smoother, not rougher, producing an anomalous response if one were to use both friction noise and the Oakridge method. Similarly, although the Kamps algorithm may work satisfactorily with the “first” scuff, there are clearly going to be issues with the “second” scuff peak. Another form of analysis is needed.

The following graph shows an instantaneous friction signal plotted between the peak friction at the beginning of the stroke and the maximum friction at the end of the stroke.



Plotting the variance of each friction data point (squared deviation from mean) for the truncated high speed friction curves gives the following:



By this measure, above 215 N and 150 C, there is a significant difference in variance between the BULK and the FAIL tests, indicating degraded performance.