THE TRIBOLOGICAL CHARACTERISITICS OF DICRONITE

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ABSTRACT

Dicronite DL5 coatings comprise tungsten disulphide (WS_2) and are deposited using a high-velocity, impingement process. These coatings offer low friction behaviour in vacuum and are relatively inexpensive. They are therefore of potential interest to the space community. However, there is little documented data to support their use in conditions representative of space mechanisms. Despite this, Dicronite films have been proposed for some forthcoming missions.

ESTL has therefore carried out a test programme to evaluate the friction and wear characteristics of Dicronite films applied by different European suppliers.

It was found that the friction and wear properties varied greatly from supplier to supplier. Coatings procured from one supplier consistently provided the longest lives and these coatings were subjected to further, more detailed, testing. In these tests, the coating performances were evaluated as a function of load, environment and speed. Testing was also carried out on ball bearings in air and in vacuum.

In sliding, the lowest values of friction coefficient measured in nitrogen and in vacuum were comparable to those of sputtered MoS_2 under identical test conditions. However, the lifetimes of Dicronite films were considerably shorter than those of sputtered MoS_2 in both sliding and in ball bearings. Like MoS_2, the wear rate and friction coefficient of Dicronite were appreciably higher in air than in vacuum.

1. INTRODUCTION

Dicronite DL5, referred to as "Dicronite" in this report, is a proprietary "precision boundary lubricant" coating which comprises tungsten disulphide (WS_2). The coating is prepared by an impingement process which has a maximum thickness of 0.5 microns and therefore has potential for lubricating precision tribo-components. 'Dicronite' is a trademark of the Dicronite Corporation of the U.S. There are a number of licensed suppliers of Dicronite coatings of which several are located within Europe.

Tungsten disulphide is part of the metal dichalcogenide family of compounds and, as such, has very similar chemical and structural properties to molybdenum disulphide. The latter material (MoS_2) is well established as a solid lubricant for use in vacuum and space applications and for precision components. MoS_2 is normally applied by the technique of sputtering. Since the Dicronite process is relatively inexpensive, it has created much interest in the space community as a possible cheap alternative to sputtered MoS_2. However, little documented or detailed evidence exists of the lubricating properties of this coating under operating conditions that are representative of those occurring in spacecraft mechanisms. It was for that reason the present study was undertaken Its purpose was to obtain some fundamental knowledge on the friction and wear properties of Dicronite coatings in air and in vacuum.

2. SCOPE OF WORK

This paper details the findings from an experimental test programme to assess the tribological performances of Dicronite coatings applied to 52100 steel discs and to ball bearings. Comparisons were made with analogous results for discs coated with sputtered MoS_2. The test programme comprised the following:

- Repeatability study: Dicronite was applied to steel discs by three different European suppliers (referred to as Suppliers A, B and C in this paper). Five treated discs from each supplier were tested to assess repeatability of the frictional characteristics and lifetimes of the films.
- Detailed assessment: one supplier's Dicronite coating was down-selected on the basis of its tribological performance and a detailed investigation of the effects of load, speed and environment carried out. The effect of dwell time (i.e. the effect of the length of inactive periods on re-start friction) in vacuum was also investigated.
- Ball bearing testing: finally, testing was carried out on a ball bearing pair, lubricated with Dicronite, in air and on another pair in vacuum.

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Throughout, comparisons were made with the performance of sputtered MoS_2.

3. GENERAL INFORMATION

Some information on the characteristics of Dicronite DL5 are available on the Dicronite web site where comparisons are made with MoS_2. The following trends are evident:

- Dicronite outgasses less than MoS_2 (it follows that since MoS_2 has an acceptable rate of outgassing, then this must also be true for Dicronite).
- At temperatures up to approximately 370 deg C, the oxidation rate of Dicronite is less than that for MoS_2. Above approximately 370 deg C, the converse is true.

The Dicronite literature also provides information regarding friction coefficient as a function of contact pressure, although no additional details are provided for the test set-up, operating conditions or the test environment. However, from this information, the frictional characteristics appear to be similar to those of MoS_2.

4. TEST PROGRAMME

4.1 Repeatability Study

This work was carried out on a pin-on-disc tribometer in which an uncoated 7.14mm diameter, 52100 steel ball was loaded against a Dicronite-coated hardened steel (52100) washer (type INA WS81102, with dimensions 28 mm OD, 15 mm ID and 2.75 mm thick). A normal load of 20 N was applied to the ball and rotation was started from zero and slowly increased to 100 rpm over approximately 20 to 50 revs and then further increased to 500 rpm after 500 revs. The radius of the test track was 11.5 mm. All testing was carried out at room temperature in a dry nitrogen gaseous environment.

Tests were carried out until the friction coefficient exceeded 0.3, at which point motion was terminated by a trip circuit. The frictional force was monitored continuously during testing on a low-frequency (<10 Hz) chart recorder.

4.2 Detailed Assessment

For these tests coatings were procured from the supplier that supplied the best performing coatings as judged by the repeatability tests (above). Testing was carried out in a vacuum-tribometer using a single uncoated 7.14mm diameter, 52100 steel ball loaded against a Dicronite-coated hardened steel (52100) disc. Testing was carried out as shown in Table 2 to assess the effects of load, speed, environment and effect of dwell on the frictional and lifetime performances of the coatings. All tests were undertaken at room temperature.

Table 1: Test matrix for detailed assessment

Environ-ment	Load (N)	Speed (rpm)	Objective
Air	10	200	Effect of environment
High vacuum	10	200	Effect of environment
High vacuum	3.3	200	Effect of load
High vacuum	5	200	Effect of load
High vacuum	20	200	Effect of load
High vacuum	10	1 to 200	Effect of speed
High vacuum	10	1, 10 & increase to 200	Effect of dwell
Dry N_2 gas	10	200	Effect of environment

Dwell times: 10 sec, 100 sec, 1,000 sec, 10,000 sec.

4.3 Ball Bearing Testing

Two ball bearing pairs were tested, one pair in air and one pair in vacuum. The bearing details are provided in the following Table.

Table 2: Ball bearing details

Parameter	Details/value
Bearing type	FAG B7004C
Ring and ball material	52100 steel
Cage type and material	Stainless steel
OD (mm)	42
ID (mm)	20
W (mm)	12
Ball diameter (mm)	6.35
Inner ring conformity	1.07
Outer ring conformity	1.08
Free contact angle (degrees)	15
No of balls	11
Preload (N)	55
Mounting configuration	Back-to-back
Lubricant	Dicronite applied to rings, balls and cages
Mean Hertz stress at inner raceway (MPa)	580, for an axial preload of 57.5N

For the air test, the failure point of the lubricant as defined as the point at which the torque exceeded three times the steady-state value. In vacuum, lubricant failure was defined as the point where the friction coefficient exceeded 0.3.

5. RESULTS

5.1. Repeatability Study

Figs. 1 to 3 show the friction and lifetimes of Dicronite films procured from Suppliers A, B and C. All measurements were made under dry nitrogen gas.

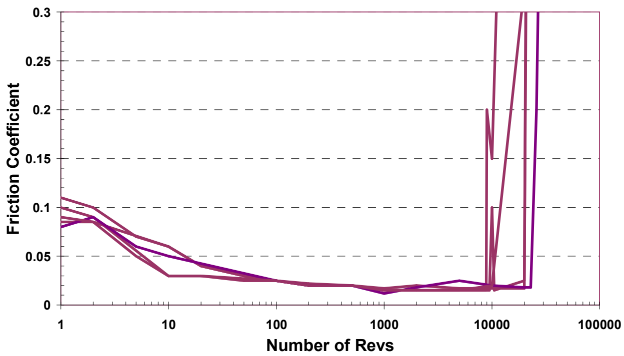

Figure 1: Test results – Supplier A (dry nitrogen)

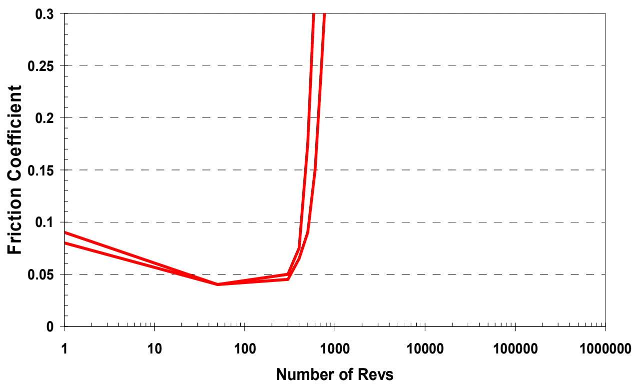

Figure 2: Test results – Supplier B (dry nitrogen)

Fig. 4 compares the average lifetimes of the Dicronite films as measured under dry nitrogen and Fig.5 compares these same results with the life of sputtered MoS_2 films tested under identical conditions.

It is clear that there is a large variation in the life of Dicronite films from supplier to supplier and that the life of sputtered MoS_2 is 2 to 3 orders of magnitude longer than Dicronite (in dry nitrogen).

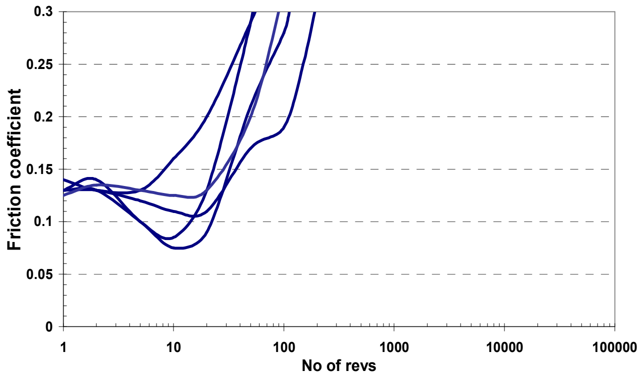

Figure 3: Test results – Supplier C (dry nitrogen)

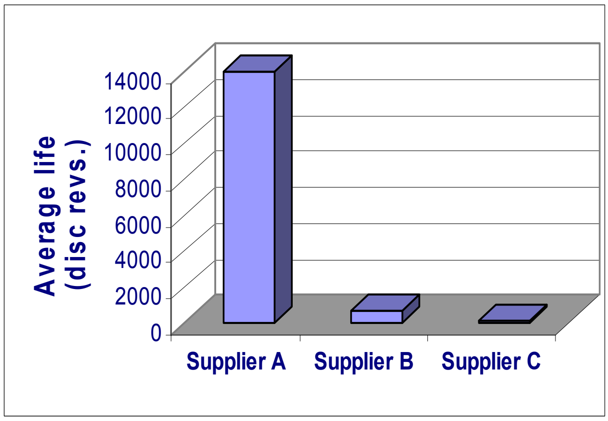

Figure 4: Comparisons of Dicronite film lifetimes

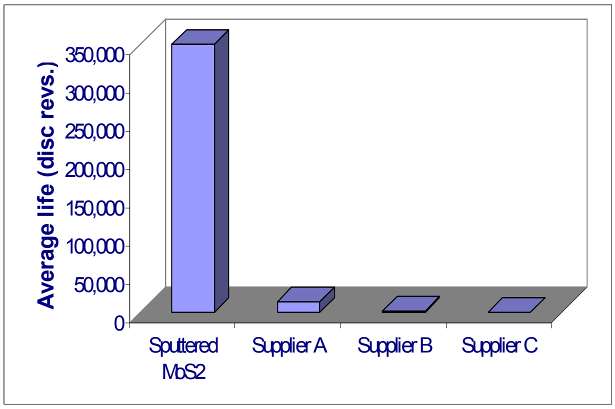

Figure 5: Comparison with sputtered MoS_2

5.2 Detailed Assessment

The effect of different test environments and temperatures upon the friction coefficients and film lifetimes were investigated. For this detailed assessment coatings were procured form Supplier A. Testing at room temperature was carried out in air, vacuum and nitrogen gas and additional tests were performed in vacuum. The test results are provided in Figs. 6 to 9.

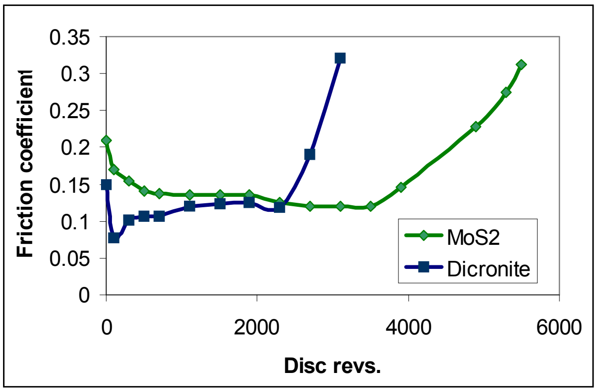

Figure 6: Pin-on disc data for Dicronite in air (corresponding data for sputtered MoS_2 is also shown)

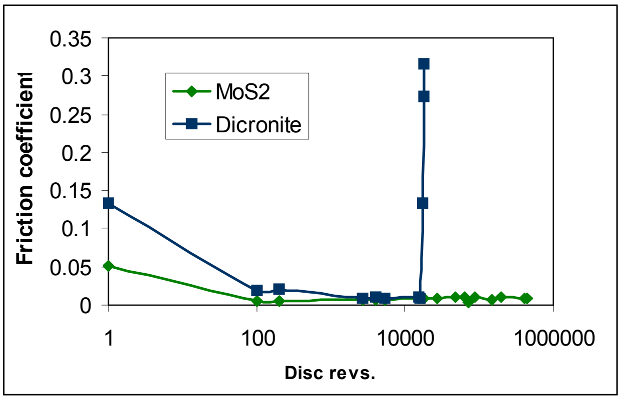

Figure 7: Pin-on disc data for Dicronite in vacuum, compared with sputtered MoS_2

The following observations can be made from the environmental tests on Dicronite coatings:

- The wear life and friction coefficient are significantly higher in laboratory air than in high vacuum.
- The friction coefficients and wear life were broadly similar in vacuum and dry nitrogen environments
- The friction coefficients in all vacuum tests ranged between 0.01 and 0.04 over their steady-state period.

It was observed that the friction coefficient is not sensitive to load variations from 3.3 to 20N. However, the films showed a general trend of decreasing life with increasing load (Fig.8). Note that a single test was carried out at each load and further testing would be required to provide a complete range of statistical data.

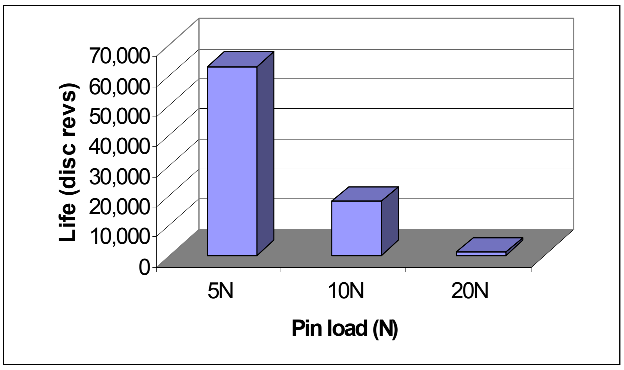

Figure 8: Effect of load on Dicronite film durabilities (in vacuum)

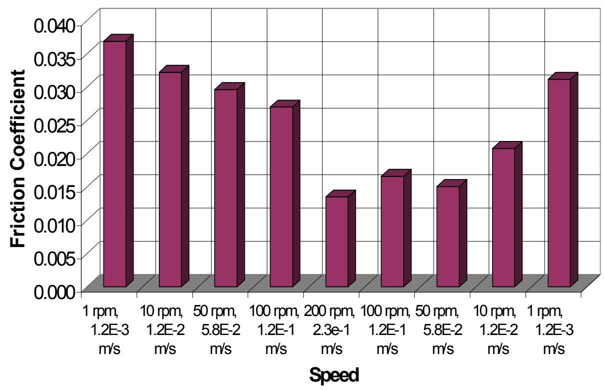

Figure 9: Effect of speed on friction coefficient of Dicronite films (in vacuum)

The effect of sliding speed on friction coefficient (in vacuum) is shown in Fig.9. These results demonstrate that increasing the speed results in a decrease in friction coefficient and vice versa. From 200 to 1 rpm, the friction coefficient increased by a factor of approximately 2.5.

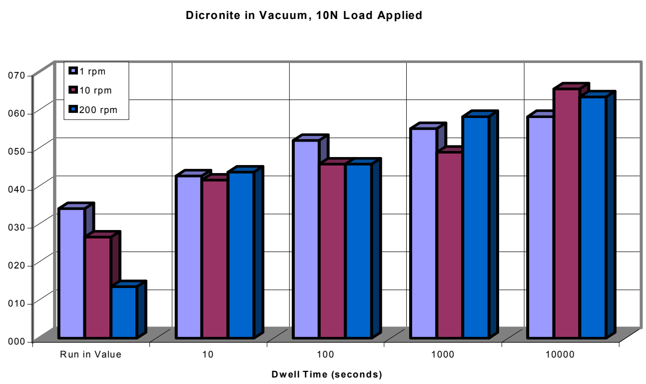

Figure 10: Effect of dwell time on Dicronite friction (in vacuum)

Fig. 10 shows the effect of dwell in vacuum. In these tests the Dicronite has been run-in under vacuum to yield low friction and then the test stopped for a defined 'dwell' period. The charts show the friction coefficient upon re-starting the test. These results demonstrate that increasing the dwell time results in an increased friction coefficient. This effect can be seen for all three test speeds. A similar phenomenon is observed with sputtered MoS_2.

5.3 Ball bearing tests

Two ball bearing pairs were tested (Fig. 11) and plots of the mean torque vs. number of revs. completed are shown in Fig.12. In air, the bearing mean torque quickly exceeded 50 gcm, corresponding to a friction coefficient greater than 0.5. The bearing pair was operated for longer to find out if the torque would eventually decrease with more revs., but this was not the case and the test was stopped at 30,000 revs.

In vacuum, the bearings required a run-in of ~6,000 revs to establish their lowest operating torque regime, which corresponded to a friction coefficient just less than 0.1. Bearing failure occurred at 112,000 revs when the friction coefficient exceeded 0.3.

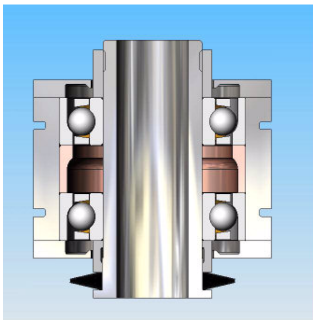

Figure 11: Ball bearing test set-up

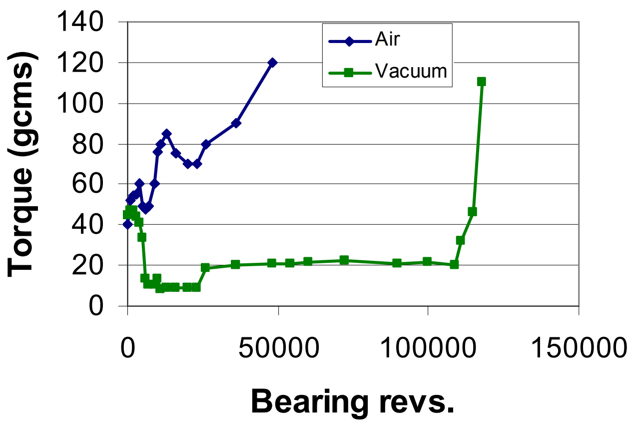

Figure 12: Bearing torque test results in air and in vacuum

6. SUMMARY AND DISCUSSION

6.1. Repeatability Study (dry nitrogen)

The quality of Dicronite DL5 coatings (in terms of friction and life) varied greatly from supplier to supplier. The longest lasting coatings, provided by Supplier A, and yielded lives in the order 20,000 revs under the test conditions applied. The shortest lasting Dicronite films survived 100 revs. only. For comparison it is noted sputtered MoS_2 coatings (ESTL) when tested under identical conditions have lifetimes of typically 400,000 revs.

The friction coefficients of the better performing Dicronite coatings were similar to those obtained with sputtered MoS_2 tested under otherwise identical conditions.

6.2 Detailed Assessment (vacuum & air)

Testing Dicronite coated discs in air resulted in the friction coefficient being between 0.08 and 0.12 with coating failure ($\mu > 0.3$) occurring on completion of some 3,000 revs. A sputtered MoS_2 disc was tested in air for comparison, this resulted in a friction coefficient of between 0.12 and 0.14 with coating failure occurring on completion of some 5,500 revs.

The lifetimes of Dicronite films in vacuum were (at room temperature) some six times longer than in air.

The Dicronite films tested did not show any clear dependence of friction coefficient upon the applied load, although there was a trend towards decreasing lifetimes with increasing load. The loads applied corresponded to mean Hertzian contact stresses of 568 MPa to 1 GPa.

Increasing the speed resulted in a decrease in the friction coefficient of the Dicronite films. This effect is consistent with the behaviour of sputtered MoS_2 films applied to hardened steel discs tested at a mean Hertzian contact stress of 571 MPa, although the MoS_2-film speed dependence is less pronounced, with the friction coefficient being 0.01 to 0.012 over the range of speeds equivalent to those used for testing Dicronite. At speeds less than 0.01 ms^{-1}, the MoS_2 films exhibited a more pronounced speed dependence, similar to that observed for Dicronite films at higher sliding speeds.

Increasing the dwell time resulted in an increase in re-start friction. From 10 to 10,000 seconds delay, the friction coefficient increased by a factor of up to 5 (depending on speed).

6.3 Ball Bearing Testing

- In air, the bearing torques corresponded to friction coefficients greater than 0.3 throughout testing, with a maximum of 0.75 measured before the test was stopped. Examination of the bearings indicated that the lubricant on the raceways, balls and cages had been completely removed at the tribological interfaces, although there was some still present on the inner ring lands.

- In vacuum, corresponding friction coefficient levels of less than 0.1 were obtained after running for 6,000 revs, although the bearing friction doubled approximately half-way through the test and the bearing pair failed at 112,000 revs. In comparison similar bearings lubricated with sputtered MoS_2 exhibit equivalent friction coefficients of between 0.02 and 0.05 and will operate at these values for up to a 3 million revs with steel cages, Ref 1.

7. CONCLUSIONS

At their best, Dicronite DL5 coatings can in vacuum provide low friction in sliding applications ($\mu < 0.02$) and an acceptable level of endurance for low duty applications only.

At their worst, coating life is too low to be considered even for low-duty applications.

Coating quality and quality control are issues that must be resolved if Dicronite DL5 is to become a serious candidate as a lubricant for precision spacecraft applications.

8. REFERENCES

1. ESTL, *Space Tribology Handbook (3rd Ed)*

ACKNOWLEDGEMENTS

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