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New Anti-Fretting Wear Test for Greases

by

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INTRODUCTION

Fretting corrosion is a persistent wear problem when contacting surfaces experience oscillatory motion of small amplitude. Fretting corrosion is characterized by the generation of large quantities of corrosion products, especially metal oxides, by unlubricated contacting surfaces.

Fretting wear is the removal of material and surface damage without significant corrosion. This includes lubricated contacting surfaces experiencing relative oscillatory slip of small amplitude. With lubricated contacts, fretting wear precedes fretting corrosion and is the desirable low wear stage. No significant metal corrosion is involved. This paper is limited to lubricated fretting wear.

Appendix 1 defines other terms used in this field of tribology.

Figures 1 and 2, show the difference between fretting wear and fretting corrosion. With lubricated contacts, fretting wear occurs first during an induction stage A, producing ordinary wear fragments. Micrographs of separated surfaces after fretting wear of a steel ball vibrating against a steel flat are shown in the top photographs of Figure 2. The grease was darkened slightly by fine black wear fragments. Wear rate was low. The wear fragments accumulate around the point of contact.

(FIGURES 1 AND 2)

However, when the accumulation of wear particles is sufficient to dam off, or soak up the oil, stage B fretting corrosion, occurs at a much higher rate of wear. During the fretting corrosion stage, steel produces the characteristic reddish debris and films consisting of the iron oxide alpha Fe_2O_3, which is the mineral hematite.

The microscopic appearance of of the wear scars are shown in the bottom photographs of Figure 2. If one observes the brown- reddish debris of fretting corrosion, the areas of real contact were unlubricated or "dry".

Some lubricants allow fretting wear to advance to fretting corrosion faster than others by a higher rate of generation of wear fragments. Operators of equipment with components subject to fretting corrosion should select a grease that will prolong the fretting wear stage. However the properties of a grease that prolong fretting wear are not generally known. (Appendix 2 provides details of a literature survey on the effect of lubricants on fretting wear and fretting corrosion.) The objective of this work was to provide test data that would provide guidelines for selecting the best grease for fretting wear.

ASTM Standard Test Method D 4170-93, entitled "Standard Test Method For Fretting Wear Protection by Lubricating Greases", measures grease performance by the weight loss of two thrust bearings oscillated 12 degrees, at 1800 cycles per minute and a load of 550 lbf for 22 hours. However, in this test fretting wear converts to fretting corrosion at an unknown time; it does not separate fretting wear from fretting corrosion. D 4170-93 is not suitable for understanding grease performance. If the reddish brown fretting debris is observed on the test bearings, the weight loss was possibly due to factors other than the grease.

This paper describes a new laboratory apparatus for measuring the anti-fretting wear properties of greases. The ball to flat point contact represent one of the areas of real contact between two surfaces, such as a bolted flange. The results show that greases which form an anti-wear film gave the lowest fretting wear.

APPARATUS AND PROCEDURE

(FIGURE 3)

As shown in Figure 3, the apparatus causes a 1/4 inch diameter ball to vibrate against a flat stationary specimen at a known load, frequency, amplitude and number of cycles. The metals chosen for these tests were low carbon steel against low carbon steel to represent common steel structures. The grease variables were the composition of the base oil, the gelling agent, fillers, and anti-wear additives.

The ball is gripped by a collet in a holder at the end of a 11 inch long vibrating beam. The ball is vibrated at 0.002 inch amplitude, because it is 1 inch from a pivot and the other end, which is vibrated at 0.020 inches, is 10 inches away from the pivot. The 0.020 inch vibration is by an eccentrically mounted ball bearing on the shaft of a 3000 rpm spindle. The flat specimen is held at the end of a loading beam where the distance to the pivot and the pivot to the loaded end were both 5 inches. Load was applied by weights on a pan-cable arrangement.

The metals used were:

vibrating ball - 1/4 inch diameter SAE 1008 steel, hardness 28 RC surfaces roughness estimated to be 1 micro inch CLA (polished), used as received (after cleaning).

stationary flat - 1/8 X 1/2 X 1 inch SAE 1018 cold rolled steel, the large surfaces were resurfaced by hand lapping on 600 grit abrasive paper ending with random direction motions.

The operating conditions were:

load - 1000 grams of force, or 9.8 Newtons,

amplitude - 0.002 inches (50 micrometers)

frequency - 50 cycles/second, by 3000 rpm shaft.

time - 60 minutes run, or 180,000 cycles, or 720 inches (18.2 meters) sliding distance.

The cleaning procedure for specimens and holders was:

scrubbing with laboratory tissues and ultrasoneration for 5 minutes each, consecutively, in heptane, acetone, and pentane followed by warm air drying. Thereafter specimens were handled only with tongs or cotton gloves.

10 milligrams of grease was applied to the ball before assembly. Commercial greases were tested and some anti-wear additives were added to a few greases.

The amount of wear was determined by microscopic measurements of the dimensions of the wear scars. The condition of the wear scars was judged from the microscopic appearance.

RESULTS AND DISCUSSION

(TABLE 1)

The test results are presented in Table 1. Figures 4 and 5 demonstrate the range of wear obtained. Figure 4 shows no visible wear fragments in the grease in the contact, which is consistent with the small wear spots found underneath the grease and shown in the bottom micrographs. The apparent pressure in the contact was 283 N/mm^2 (41000 lbs/in^2).

In contrast, Figure 5 shows large quantities of wear fragments collected in the grease, and large scuffed wear scars. In this contact the apparent pressure was 41 N/mm^2 (6000 lbs/in^2).

(FIGURES 4 AND 5)

Repeat runs, shown in the table, indicated a wear scar size repeatability of + or - 0.04 mm.

The smallest fretting wear was obtained with greases which formed anti-wear films on the contacting surfaces. The films reduce wear by preventing or reducing metal to metal contact . Although the chemistry of film formation was not clear, the greases that gave the lowest wear contained PAO base oil and polyurea gelling agent, and those containing MoS_2 or calcium sulfonate.

CONCLUSIONS

A laboratory apparatus was developed which is suitable for testing and understanding the anti-fretting properties of greases. Metals and operating conditions of load, and vibration frequency can be selected to simulate field conditions.

APPENDIX 1

OTHER RELATED TERMS

Other related terms are :

Friction oxidation is synonymous with fretting corrosion.

Fretting fatigue is the fatigue failure of a part caused and accelerated by fretting wear and fretting corrosion. Pits from fretting corrosion create local stress concentrations and cracks; high friction causes high tangential stresses which accelerate crack growth.

False brinelling is a different wear mechanism, defined as the formation of depressions on the races of rolling element bearings due to localized wear. The localized wear is a result of small oscillatory rotation or rocking of the rolling elements when the bearing is vibrating, but not rotating. The location of the depressions match the positions of the rolling elements.

Grease is a lubricating oil gelled by a "thickener" such as soap. Some greases contain insoluble solid "fillers" such as molybdenum disulfide and poly tetrafluoroethylene powders. The oil weeping from grease is the primary lubricant.

Rust is the corrosion product of ferrous metals by air and water forming the hydrated iron oxide $Fe_2O_3.H_2O$, the minerals goethite and lepidocrocite. They can be distinguished from hematite ($Fe_2 O_3$) only be X-ray or electron diffraction, because of different crystalline structures.

Magnetite Fe_3O_4, is one of the surface oxides of ferrous metals. Magnetite is black, magnetic, and a common wear fragment produced by oil lubricated steel under mild sliding conditions.

APPENDIX 2

Literature Survey

Occurrence

Fretting wear and fretting corrosion will occur on any contacting surfaces where vibration, misalignment, or other conditions cause slight relative reciprocating sliding of low amplitude, such as 0.0005 to 0.005 inches. The most susceptible machine parts are:

base plates, flanges and bolted assemblies,
spline couplings,
steel rope,
bore and outside diameter fit surfaces of rolling element and sliding bearings,
universal joints,
constant velocity joints,
aircraft hinges and control surfaces,
keys, bores, and shafts of gears,
oscillating bushings and pins,
pivots of tilting pad bearings,
electrical contacts.

Prevention

The prevention of fretting wear and fretting corrosion is of universal concern primarily because they can lead to fatigue failure. The only permanent prevention is to stop the sliding motion between the surfaces by redesign. Stopping sliding may be as simple as tightening a fit or tightening bolts on a flange to increase the friction. Most other methods are palliative. The general objective is to separate the surfaces to prevent metal to metal contact by thin coatings of rubber, platings of soft metals, solid lubricant coatings, and lubrication with pastes, oils and greases. (Reference 3)

A review of the literature on the properties of oils and greases that had an effect on fretting wear and fretting corrosion was conducted. Flooding a part, such as a spline coupling, with oil, reduced fretting ten times more than greases (4, 5).

Oil

Bronshtein, L. A., et al (6) found that esters and mineral oils with phosphorous containing additives gave small fretting wear scars.
Neyman (7) found that oil viscosity had a minor effect, but oils with the highest load capacity on a four-ball lubricant tester gave the lowest fretting wear. McColl, et al, (8) investigated lubricants to reduce steel rope fretting and thus extend rope life. A mineral oil with dispersed graphite was best. Muller (4) found that a tricresyl phosphate additive in mineral oil, or a surface pre-etched by phosphoric acid, was effective in reducing the friction force associated with fretting corrosion. Muller also showed that a white oil and a spindle oil reduced fretting corrosion. Godfrey (1) showed that phosphorus containing additives in mineral oil reduced wear during the induction period. Sato et al (9) found that the common anti-wear additive zinc dialkyldithiophosphate in mineral oil was very effective in reducing fretting.

Greases

A rule of thumb for reducing fretting with greases has been to use one with a base oil of low viscosity based on the concept that the oil could readily flow into the areas of real contact. More recent research indicates that good boundary lubricating properties are most beneficial.

A grease was shown to be effective in reducing fretting wear in electric cables (10). Wunsch (11 and 12) showed that oil viscosity did not influence fretting in a test rig and that the addition of molybdenum disulfide powder and teflon were ineffective. The lowest fretting wear was obtained with a lithium soap gelled ester base oil, and an aluminum soap gelled mineral oil. Kato and T. Sato (13) found greases made with a polyurea gelling agent and phosphorus containing anti-wear additives gave the lowest fretting wear. Also Ku (14) showed great differences among three greases in extending the low wear-fretting stage. Schlobohm (15) and Mishima, et al (16) showed that a polyurea gelling agent in mineral oils reduced fretting corrosion. He stated "As a rule, additives do not greatly influence fretting corrosion".

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TABLE 1

Fretting Wear Grease Tests

Carbon Steel Ball vs Carbon Steel Flat, Load 9.8 N, Frequency 50 c/s, 180000 Cycles

	Grease			Scar Size, mm			Scar
No.	Base Oil	Gelling Agent	Additives	On Ball	On Flat	Average	Description
	Mineral						
1	Mineral	-	MoS2	0.24	0.29	0.27	Film
2	Mineral	-	MoS2	0.18	0.21	0.21	Film
2	Mineral	-	MoS2	0.24	0.29	0.27	Film
3	Mineral	Polyurea	-	0.36	0.36	0.36	Scuffed
4	Mineral	Polyurea	-	0.52	0.57	0.55	Severe scuff
5	Mineral	Lithium soap	-	0.40	0.45	0.42	Severe scuff
6	Mineral	Calcium sulfonate	-	0.21	0.31	0.26	Black film
6	Mineral	Calcium sulfonate	-	0.24	0.28	0.26	Black film
7	Mineral	Calcium complex	-	0.18	0.25	0.22	Film
	Blend (a)						
8	PAO/Mineral	Polyurea	-	0.49	0.52	0.46	Severe scuff
9	PAO/Mineral	Lithium soap	-	0.20	0.28	0.24	Film
	Synthetic						
10	PAO	Calcium complex	-	0.29	0.32	0.31	Scuffed
10	PAO	Calcium complex	-	0.26	0.31	0.29	Scuffed
10	PAO	Calcium complex	-	0.20	0.29	0.25	Film
11	PAO	Lithium complex	-	0.25	0.30	0.28	Scuffed
12	Ester	Polyurea	-	0.21	0.21	0.21	Sl abrasion
12+	Ester	Polyurea	Tricresyl phosphate	0.24	0.29	0.27	Sl scuff
13	Ester/PAO	Lithium soap	-	0.33	0.40	0.37	Polished
13	Ester/PAO	Lithium soap	-	0.39	0.45	0.42	Polished
13+	Ester/PAO	Lithium soap	Phosphate ester	0.31	0.36	0.34	Polished
13+	Ester/PAO	Lithium soap	Sulfurized Fat	0.28	0.33	0.31	Polished
13+	Ester/PAO	Lithium soap	Triphenyl phosphate	0.40	0.45	0.43	Scuffed

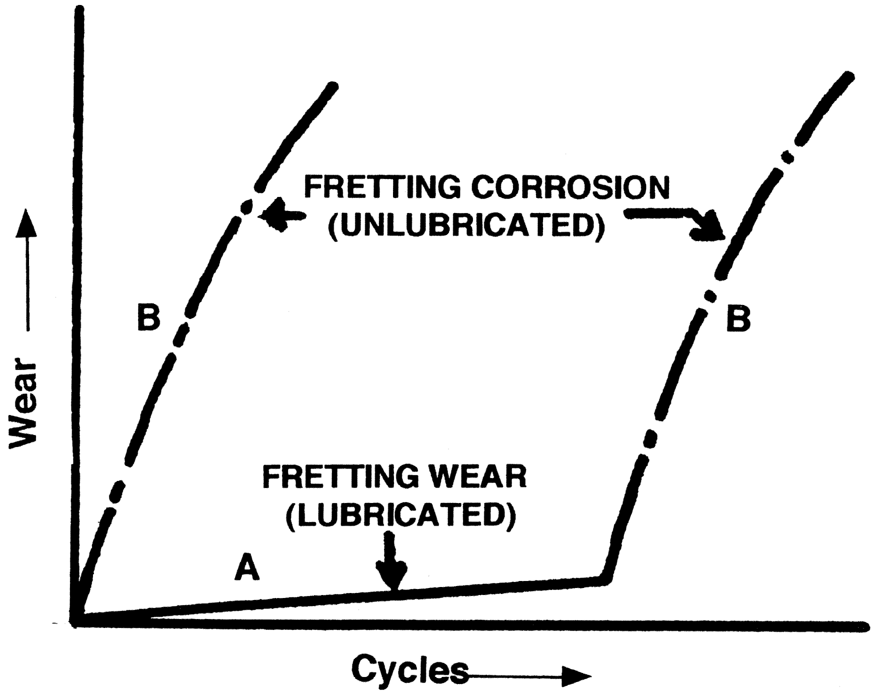
Notes (a) PAO -Poly Alpha Olefin
- Unknown
+ Added to grease

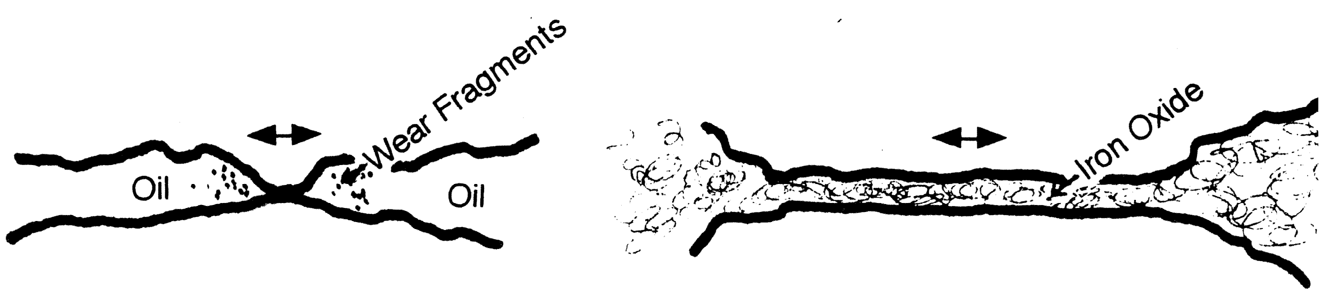
Figure 1

DIFFERENCE BETWEEN FRETTING WEAR AND FRETTING CORROSION

Steel vs Steel

From Reference 1





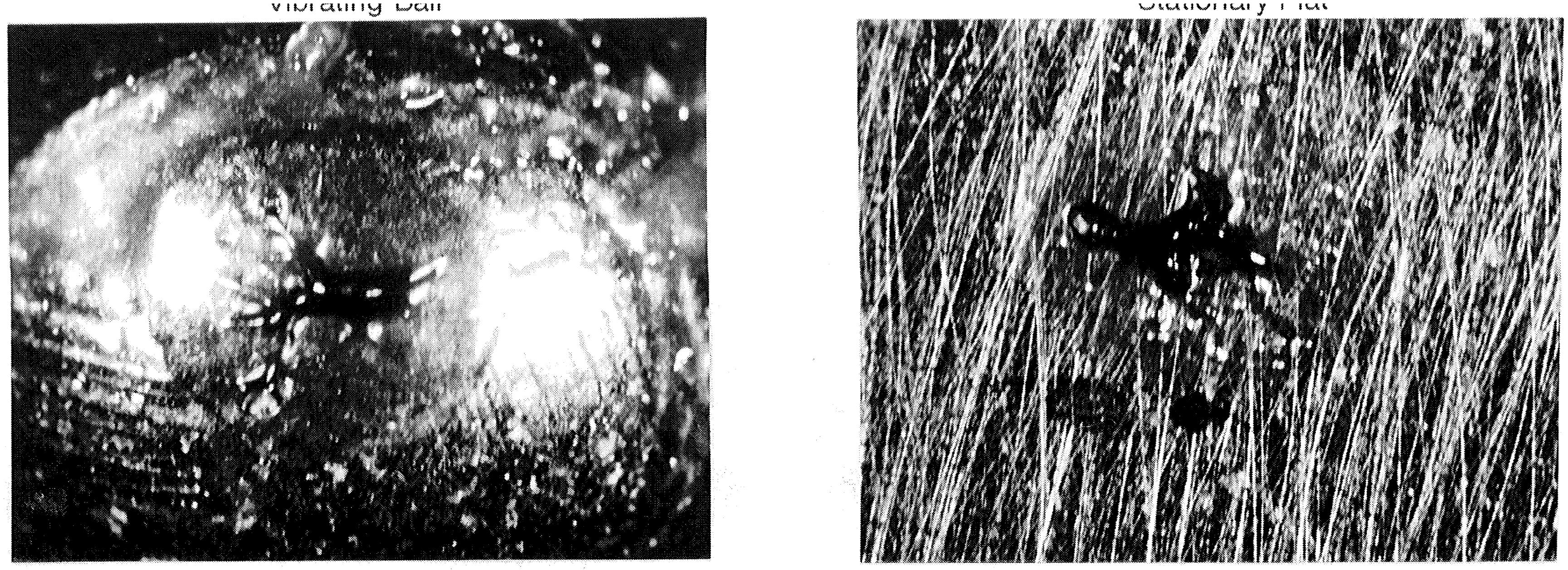
A

FRETTING WEAR
LUBRICATED
Low Wear Rate

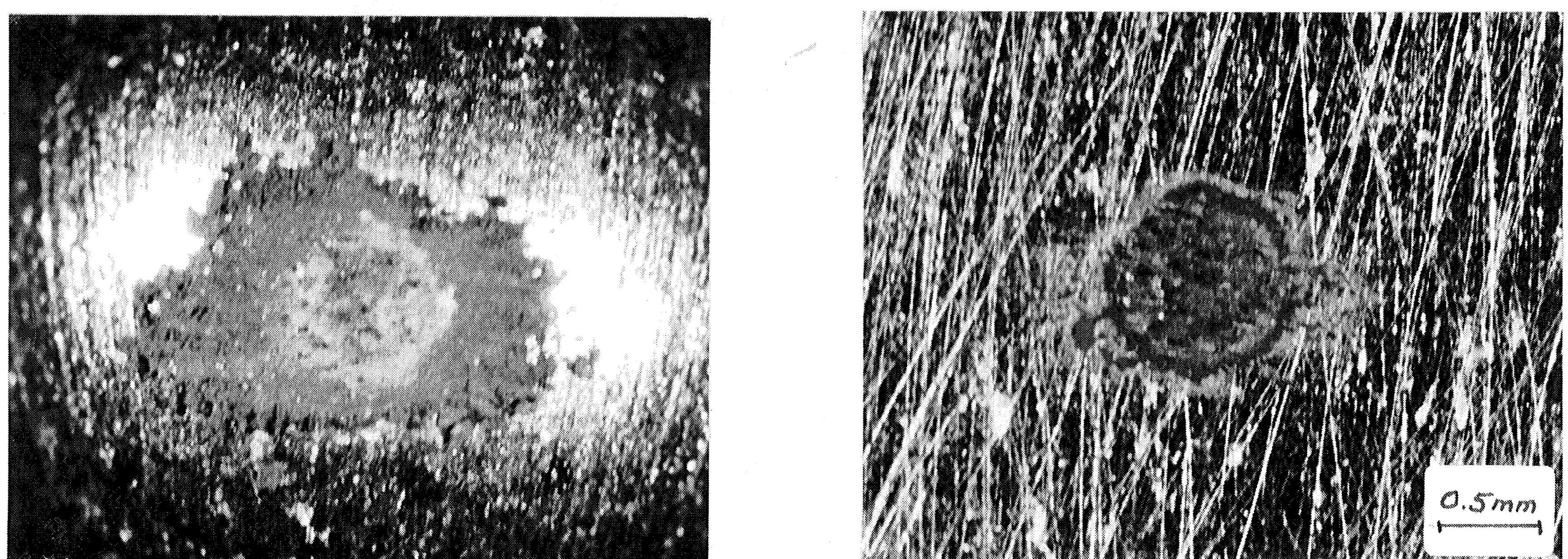
B

FRETTING CORROSION
UNLUBRICATED
High Wear Rate

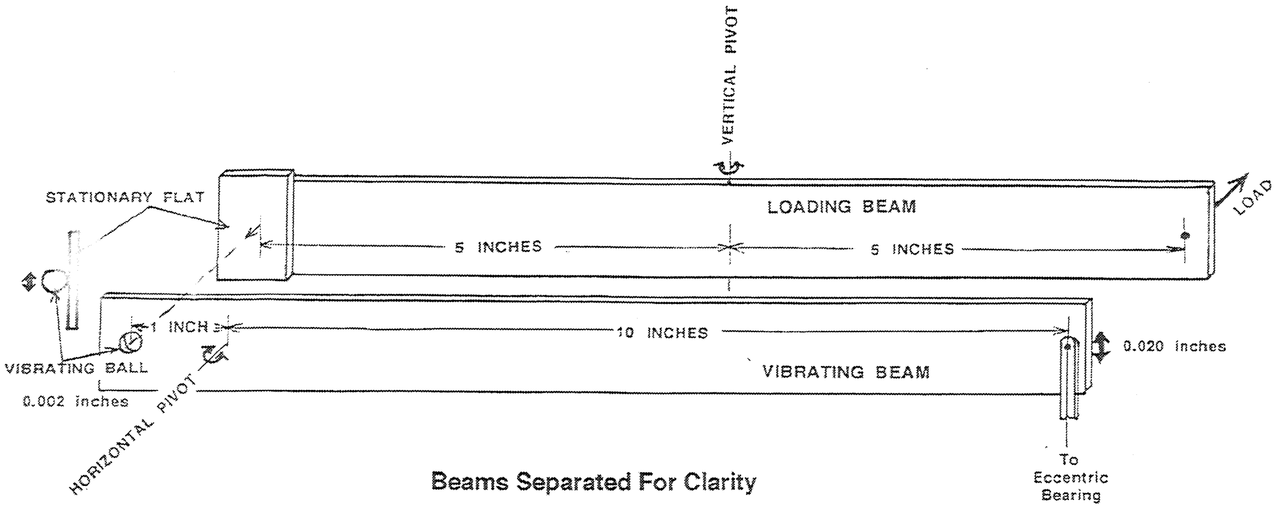
Vibrating Ball | Stationary Flat



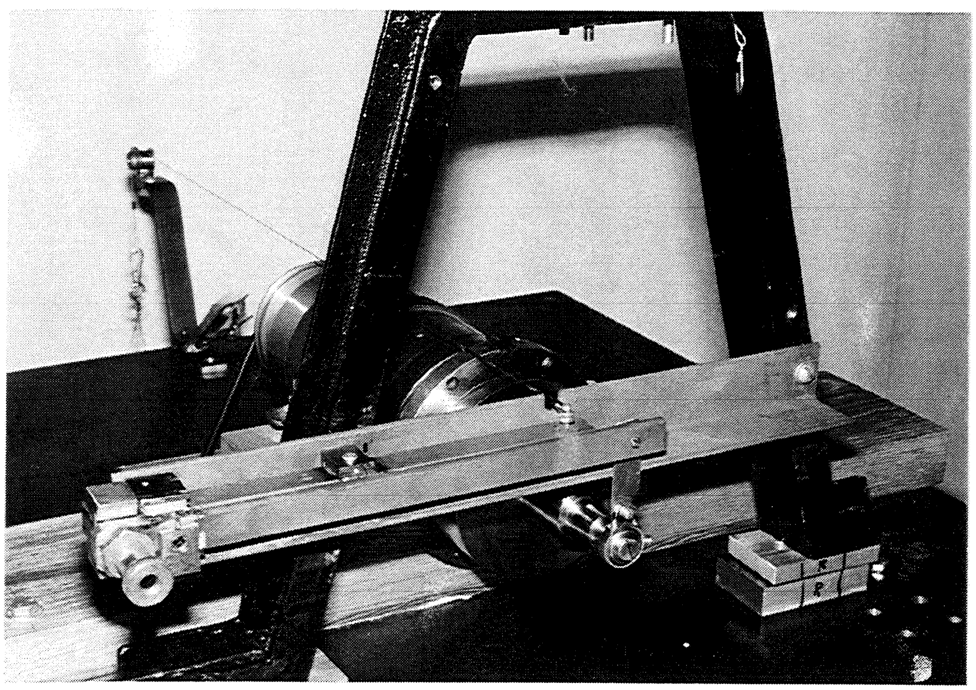
Stage A   Fretting Wear After 6000 Cycles, With Grease Present, Contaminated With Black Wear Fragments



Stage B   Fretting Corrosion After 60000 Cycles, With Grease Displaced By Red Fretting Corrosion Debris

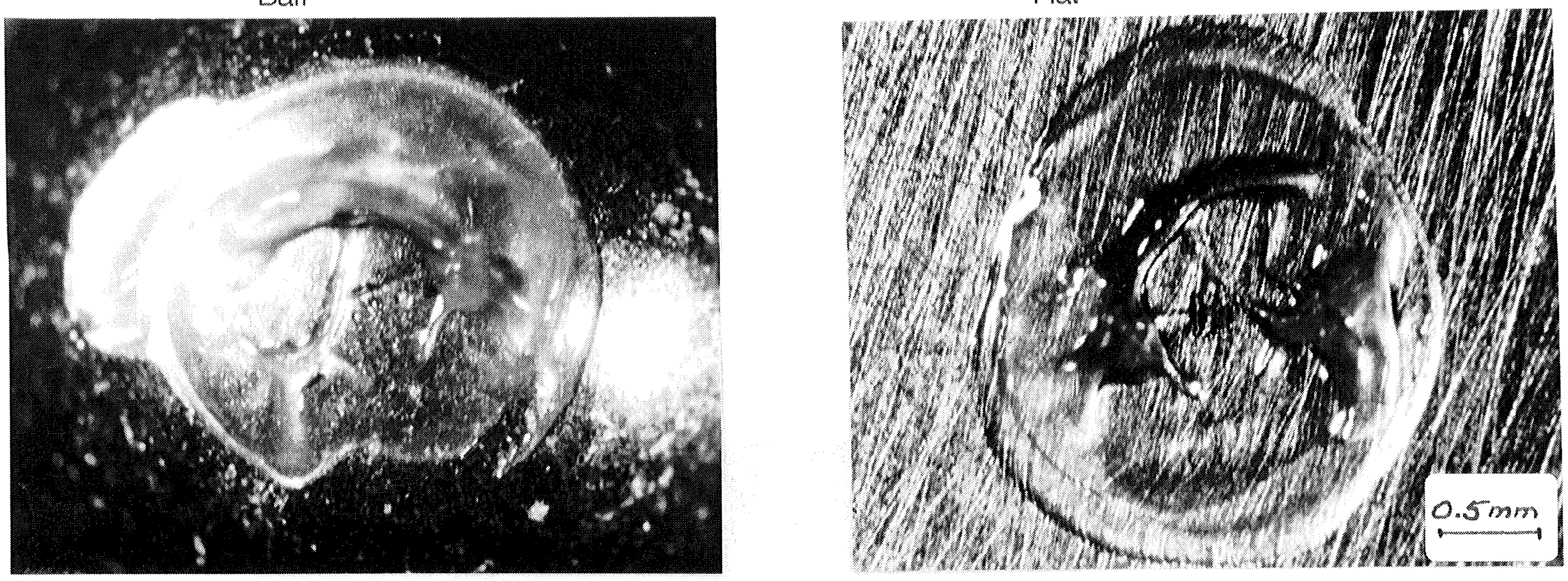


Schematic Diagram

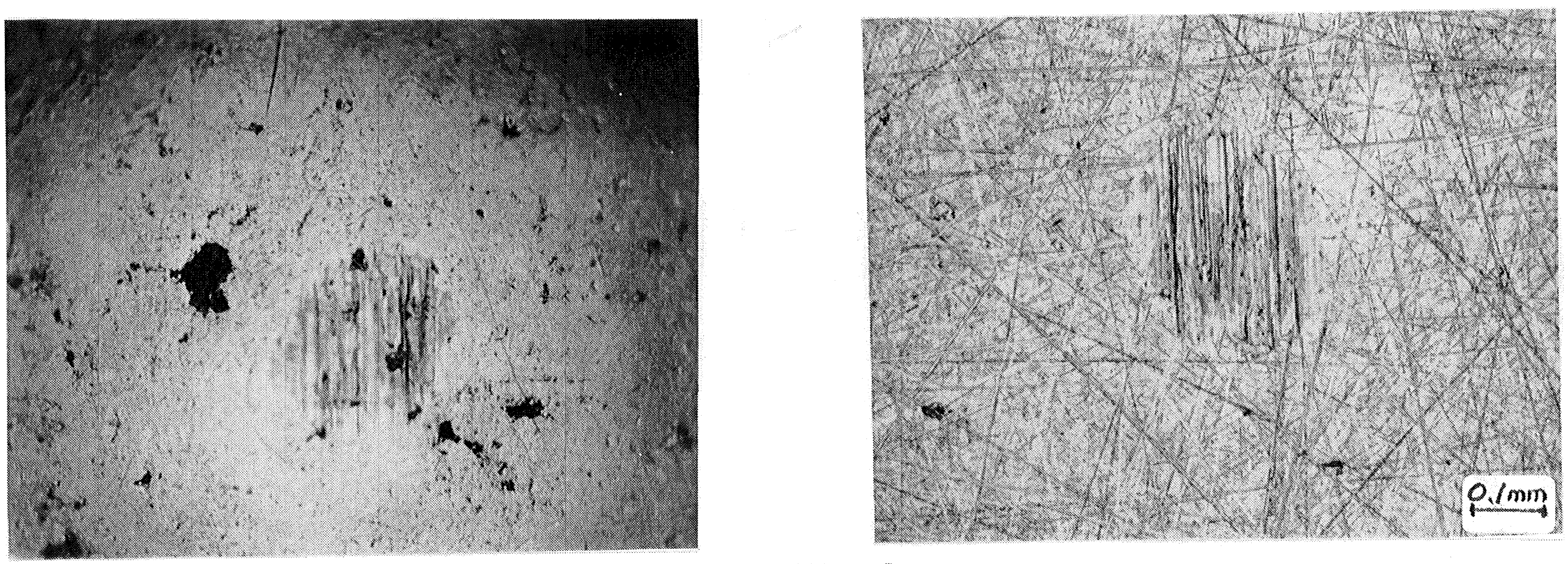


Photograph

ure 3. Fretting Wear Apparatus, Carbon Steel Ball Vibrating Against Stationary Carbon Steel Flat, Load 9.8 N, 50 Cycles/s, Ball | Flat



As Separated, Grease Not Wiped Off

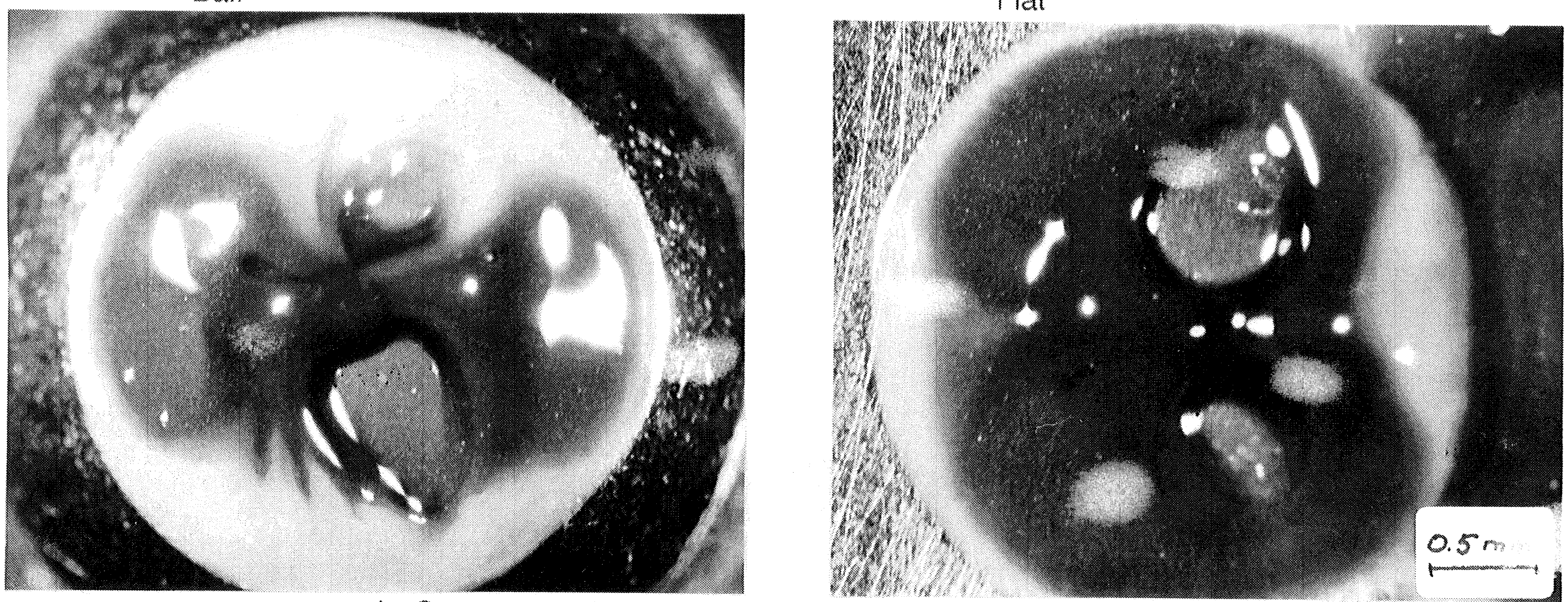


Grease Removed Revealing Wear Scars

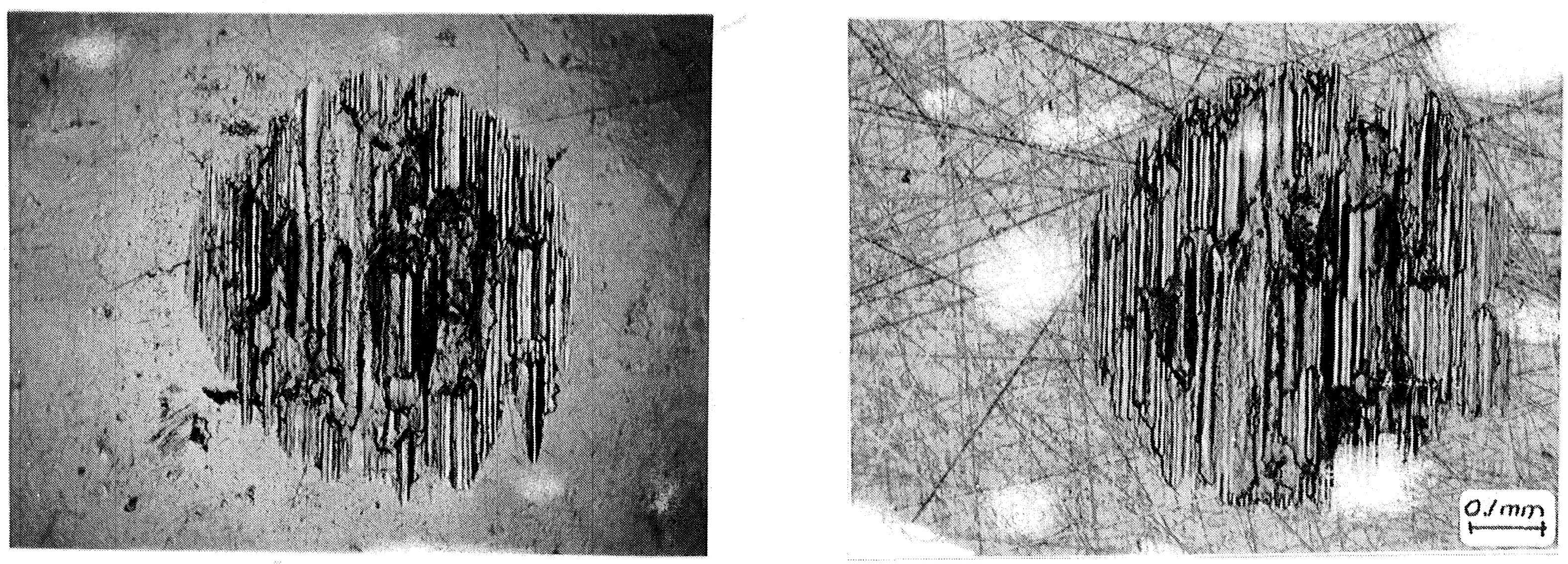
Figure 4. Micrographs of Wear Scars After Fretting Wear With Ester Base Oil/ Polyurea Gelling Agent Grease.
Carbon Steel Ball Vibrating Against Stationary Carbon Steel Flat, 9.8 N, 50 Cycles/s, 180000 Cycles

Ball

Flat



As Separated, Grease Not Wiped Off



Grease Removed Revealing Wear Scars

Figure 5. Micrographs of Wear Scars After Fretting Wear With Mineral Oil/ Polyurea Gelling Agent Grease.