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AN INVESTIGATION OF THE EFFECTS OF CERTAIN LUBRICANTS IN REDUCING FRETTING CORROSION OF CERTAIN STEELS

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AN INVESTIGATION OF THE EFFECTS OF CERTAIN LUBRICANTS

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BY

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INTRODUCTION

Fretting corrosion is a type of metal damage occurring at the interface of two contacting surfaces subject to relative slip. The maximum value of this slip according to Waterhouse (1) is about 0.008 inch. The damage to steel is evident by debris formed at the interface, usually red in color and mainly consisting of Fe_2O_3 (2,3), and accompanied by pitting of the metal. Damage of this kind is a source of uncertainty in the operation of all machinery subject to vibration, since it quickly destroys close tolerances, it increases the susceptibility to fatigue, and it generates abrasive debris (4). Examples of fretting damage are often found in variable-pitch propellers, aircraft landing wheel bearings, splined-shaft connections, railroad tie plates, pins in gear trains, and automobile universal joints.

Several approaches have been taken in the attempts to reduce fretting damage. They consist of the use of lubricants (5,6,7,8), change of design so as to avoid slip, and selection of materials with regard to the properties of fatigue resistance, surface finish, hardness, and abrasive wear resistance (9,10). These methods for mitigating damage have not always been adequate to date.

It should be noted that the use of lubricants, as discussed in this investigation, does not include forced feed type systems. In other words, the lubricant is placed in position and is subject to periodic replacement.

This report will analyze the effects of lubricants in mitigating fretting damage under controlled conditions of load, slip, frequency, number of cycles, and temperature. Most previous work has been spent in studying the basic underlying mechanisms of fretting on clean surfaces. The literature concerning the use of lubricants has been rather general. In other words, most of the previous work has been concerned with identifying the underlying mechanism of fretting corrosion. Uhlig, Feng, Tierney, McClellan, and Rightmire at Massachusetts Institute of Technology are the only ones who have made measurements under controlled conditions of slip, frequency, and pressure. There will be frequent references made to their work for purposes of correlation.

CHAPTER II

STATEMENT OF THE PROBLEM

The purpose of this investigation was to evaluate the effect of four selected lubricants upon steel subject to fretting corrosion.

The steel selected was AMS 6260E steel, which is considered representative of the steel in the splined shafts that are of concern to the USAF.

The exact composition of the lubricants that were tested is unknown, since this information was not available to the author. The lubricants that were evaluated include:

1. Plastilube III - Warren Refining Corporation
2. Molylube Sun Special - Bet Ray Corporation, Inc.
3. Pioneer Spline Lubricant Number 31 - Eclipse-Pioneer Division of Bendix Aviation Corporation
4. Lubricants conforming to MIL-G-7118A and MIL-M-7866A - Shell Oil Corporation and Alpha Molykote Corporation respectively.

The Plastilube III is a petroleum base lubricant containing major amounts of MoS_2, Silicon, and Aluminum. It has a dropping point above 500 F. The Molylube Sun Special is made up of MoS_2 and Unitemp 500 in a mixture of 50 per cent by weight. The base material of the Pioneer 31 is unknown. It has a dropping point of 447, an unworked penetration of

124, and a worked penetration of 188. The MIL-G-7118A and MIL-M-7866A combination consists of the grease and MoS_2 in a mixture of 14 to 1 by weight. The grease has a Lithium base with minor amounts of Calcium and Magnesium. It has a dropping point of 375, an unworked penetration of 270, and a worked penetration of 298. The MIL-M-7866A is apparently pure MoS_2. All of these lubricants are either being used currently or have been proposed for use in splined fittings in various constant speed drives or accessory sections of the J-47, J-57, and J-75 aircraft jet engines.

In the present work, the extent of damage was measured by the weight loss or gain of pairs of test specimens operating under defined test conditions. Weight loss or gain becomes a less precise measure of damage after corrosion assumes the shape of deep pits on the faying surfaces, since the depth and shape of the pits enter into an evaluation of their possible source as fatigue nuclei. The relative delay of the onset of fretting or corrosion as well as a study of the behavior of this corrosion in the presence of lubricants was the primary objective of these tests.

CHAPTER III

DESCRIPTION OF EQUIPMENT

The present machine was designed and constructed to produce fretting damage by oscillatory motion of two pairs of test specimens held in place by two moving and two stationary Jacobs Chucks (Figures 1 and 2). Two sizes of test specimens were used in this series of tests.

The first one was one inch in diameter by 2.500 or 2.000 inches long. One end is counterbored 0.877 inch in diameter by 0.0625 inch deep, with the resulting annular face providing the test surface (area equals 0.184 square inches at a mean radius of 0.438 inch).

The second size of specimen was made from condemned Sunstrand Drive Shafts of 0.718 inch diameter and 2.250 inch length. One end of the shaft is counterbored 0.593 inch in diameter by 0.0625 inch deep, which provides the annular test surface of 0.164 square inches.

The test surfaces are dressed on the lathe and then carefully polished by hand with 320A and 400A emery paper, and crocus cloth.

During the test two such specimens are pressed together under a measured load with the annular surfaces in contact. One is fixed in position and the other is subject to oscillatory motion sufficient to cause slip. Alignment of test surfaces is achieved through the use of a lathe bed, tail stock, and modified center feed to align the four Jacobs Chucks which in turn hold the specimens. The modified center feed allows angular and back and forth motion in the X-Y plane. Distance above the lathe bed (Z direction) is carried from the tail stock and is fixed. Specimen load can be applied to a maximum pressure of 28,700 psi for the one inch specimen and 32,300 psi for the 0.718 inch specimen. Frequency of motion can be varied between 690 and 3600 cpm. The relative slip is presently set at 0.0035 inch for the one inch specimen and at 0.0025 inch for the 0.718 inch specimen. The eccentric is designed for easy interchangeability, so that any desired relative slip can be obtained by changing the eccentric portion of the drive shaft.

Specimens are placed in the Jacobs 20N Chucks and are then secured by tightening the chuck. Use of the Jacobs Chuck allows for a wide range of specimen diameters. Relative motion between chucks and specimens cannot be detected, and observed fretting is satisfactorily restricted to the test surface.

The two moving chucks are pressed onto Jacobs Tapers which are machined onto the center shaft. This center shaft starts out with a 3 inch diameter by 2.000 inch long center section which tapers to two 2.000 inch diameter by 3.750 inch long bearing areas which, in turn, taper to the two previously mentioned Jacobs Tapers. The center shaft is mounted to the floating center rest of the lathe by means of a plate and two Dodge Type E heavy duty pillow blocks.

Oscillatory motion is imparted to the center shaft by means of a 3/4 inch diameter by 12 inch long lever arm. This lever arm is connected to the eccentric on the drive shaft by means of a shaft with two rod end bearings. This four pin arrangement allows the rotary motion of the drive shaft to be changed into oscillatory motion on the center shaft. The rod end bearings allow for misalignment as well as considerable movement of the floating center rest on the lathe bed.

The drive shaft transmits power through a series of V-belt pulleys which allow speeds of 690, 1850, and 3600 rpm. Other speeds can be readily obtained by inserting other pulleys. The driving motor, a 230-volt, three phase, 1 horsepower motor, mounted on rubber, operates at 3600 rpm.

Vibration of the machine was reduced to a minimum so as to confine observed fretting corrosion to pure radial motion of the specimens. Extraneous relative motion of the specimens during testing was checked by a steromicroscope comparator and the maximum motion found to be in the order of 0.0005 inch.

The normal load between the fixed and moving specimens is applied by a hydraulic cylinder with a separate hydraulic power source. One of the fixed chucks is mounted to the end of the hydraulic cylinder push rod which is pinned against oscillatory motion by a hinged support. This allows for loading and unloading of the one fixed specimen against the oscillating specimens of the floating center rest of the lathe. This pressure against the two center specimens is finally transmitted to the fixed specimen in the tail stock. The tail stock is anchored to the hydraulic cylinder base by means of a strap coupling. Loads up to 5000 pounds are obtainable. In terms of normal stress at the test surface of the one inch and 0.718 inch specimens, this is equivalent to 28,700 and 32,300 psi respectively.

Slip is reported as the difference in motion of the moving specimen with respect to the fixed specimen. It is measured using a 40 power steromicroscope with calibrated micrometer disc in one of the eyepieces. The microscope is focused on a line scribed across the interface of the two specimens parallel to their longitudinal axis. Stroboscopic light illuminates the specimens at a frequency slightly different from the frequency of test; hence, the lines appear to move slowly back and forth making possible a measure of their extreme positions. The measurement is made for both moving and stationary specimens and the difference taken as the observed relative slip. Reproducibility was in the order of 0.0005 inch.

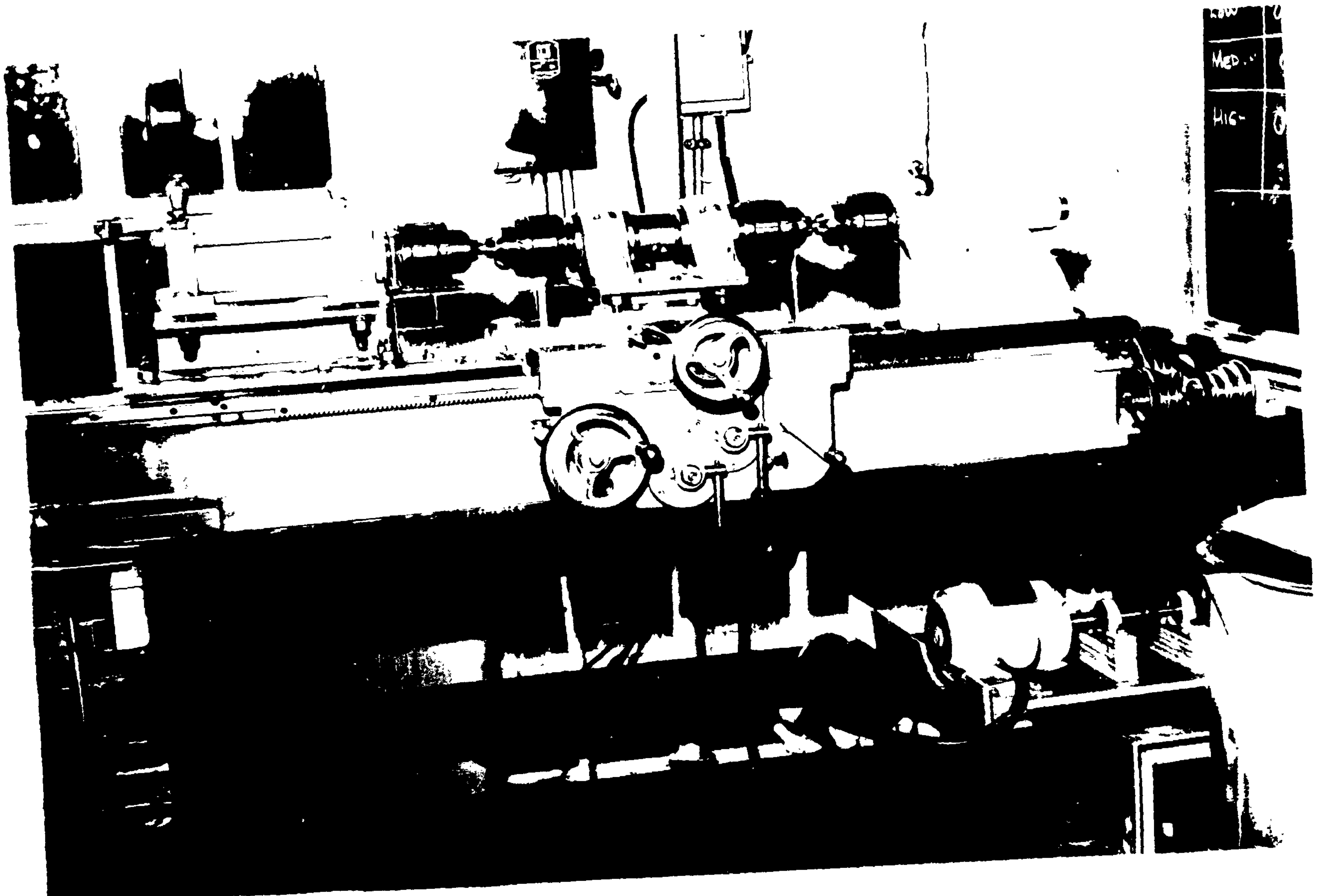


Figure 1: Full View of Test Machine

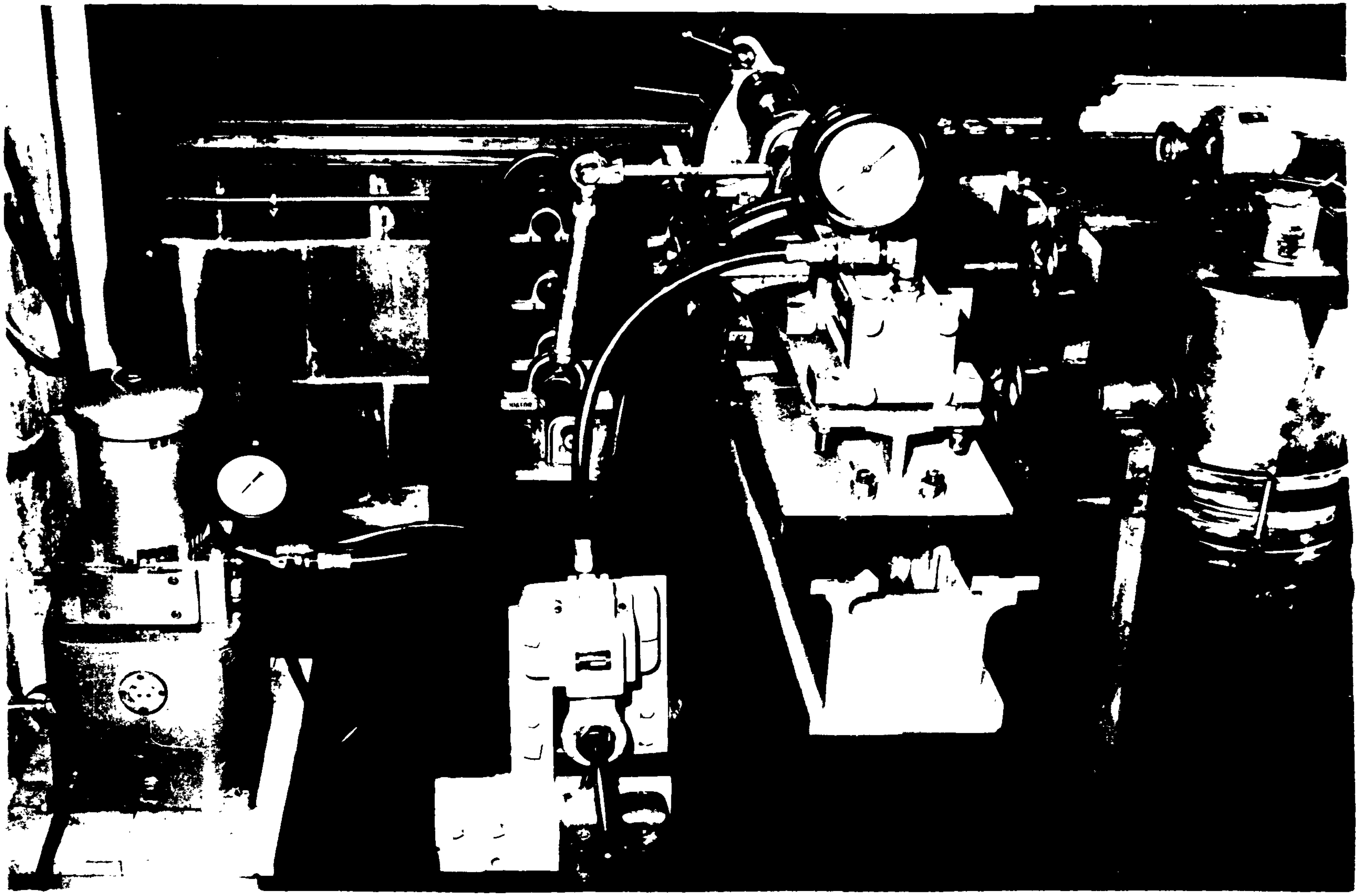
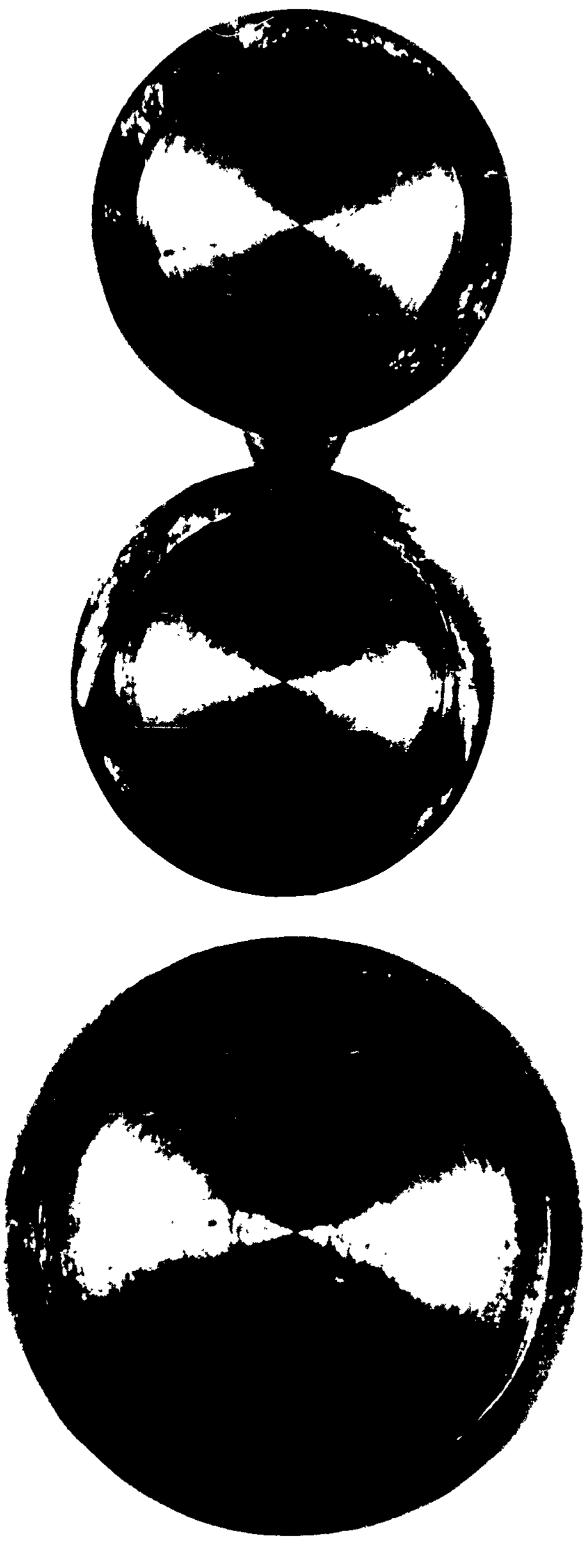


Figure [illegible]: Side View - Fretting Wear Test Machine



KEY TO COMPONENTS ILLUSTRATED

Figure 1:

1. Hydraulic Cylinder
2. Test Samples
3. Floating Center Rest

Figure 2:

4. Counter
5. Hydraulic Control Valve
6. Hydraulic Power Pack

Figure 3:

7. AMS 6260E Steel
8. SAE 1018 Cold Rolled Steel

CHAPTER IV

EXPERIMENTAL PROCEDURE

Specimens to be tested were first prepared on a lathe. Final surface finish was obtained by hand polishing with 240A, 500A emery paper and crocus cloth. The specimens were then degreased by immersion and scrubbing in hexane, air dried, and weighed. Upon completion of the test run, the specimen was again degreased with hexane. It was then immersed in a 5 per cent by weight solution of H_2SO_4 at room temperature for 60 seconds. This was followed by scrubbing in separate solutions of water and hexane, air drying, and weighing. The weight loss on the average as a result of this procedure was 0.0003 gram, which was added to all results obtained. The effect of the acid bath was checked for each set of specimens during a run and adjustments made if needed.

The first series of tests conducted on the machine were an attempt to reproduce the data obtained by Uhlig, Feng, Tierney, and McClellan (2). These tests were performed on SAE 1018 cold-rolled steel in the absence of lubricants. Data gained from these tests reproduced, on the average, the data of (2) to within 7%. There were individual differences in the test runs primarily because the test environment was not controlled with respect to humidity, which is an important variable in the fretting of steel in the absence of lubricant. The test runs were made under the following conditions: pressure-5300 psi; slip-0.0035 inch; frequency-690 cycles per minute; duration of test-67,800 cycles; and temperature 73-80 F.

The second series of tests were concerned with evaluation of the effects of selected lubricants in reducing fretting damage of AMS 6260E steel. The AMS 6260E steel averages about 26-27 on the Rockwell Hardness Scale. The specimens were prepared from condemned Sunstrand Shafts, part number 663764, from the constant speed drive of the F-102 interceptor. It was considered to be a typical steel by the Accessories Section, OCNERH, OCAMA, Tinker AFB, Oklahoma. These specimens were prepared in the previously mentioned manner and were tested under the following conditions: load 7500 psi; 0.0025 inch slip; and a frequency of 690 cpm. The total number of cycles was the variable with test points selected at 10,000; 25,000; 50,000; and 100,000 cycles.

A series of tests in the absence of lubricants was run. Since there was no humidity control, these tests were of limited usefulness in making comparisons to lubricated tests.

During the latter stages of this preliminary investigation, it was decided to vary the pressure to 2500 and 5000 psi while holding the number of cycles constant at 25,000. This was decided after a few runs that were made at 7500 psi with one specimen lubricated and one specimen dry indicated very little difference in the amount of wear.

CHAPTER V

EXPERIMENTAL RESULTS

The test machine was operated several times before actual recordable data were taken in order to determine a standard operating procedure. This also applied to the handling, preparation, weighing, etc., associated with the test specimens. It was also determined that both test locations on the test machine yielded the same results after a test run on the same material.

After the initial runs to determine standard operating procedures, it was decided to attempt to duplicate the test data of reference (2). Since the purpose of this investigation was not the study of fretting wear in the absence of lubricants, no provision for accurately controlling humidity was provided for in the design of the test apparatus. This has been shown to be a very important variable in this type of study (2). Therefore, it was decided to take the average value of a number of runs and compare it to the data in (2). The test material selected was one inch O.D. bar stock 1018 cold-rolled steel. Test parameters from (2) were: cycles-67,800; load-5300 psi; frequency-540 cpm; slip-0.0036 inch; temperature-77 F; and zero humidity. This resulted in a weight loss of 0.0078 gram. Other data from (2) predicted that weight loss decreases with an increase in humidity and that variation of frequency between 540 and 690 cpm with this amount of relative slip would contribute a negligible weight loss.

The same material and test parameters were selected with the following exceptions-690 cpm and no humidity control. The average weight loss computed after 10 test runs at an average temperature of 77 F was 0.0072 gram. This falls within 7 per cent of the standard data and, considering the restrictions, is considered verification that this test machine will produce fretting under controlled conditions (Chart 1).

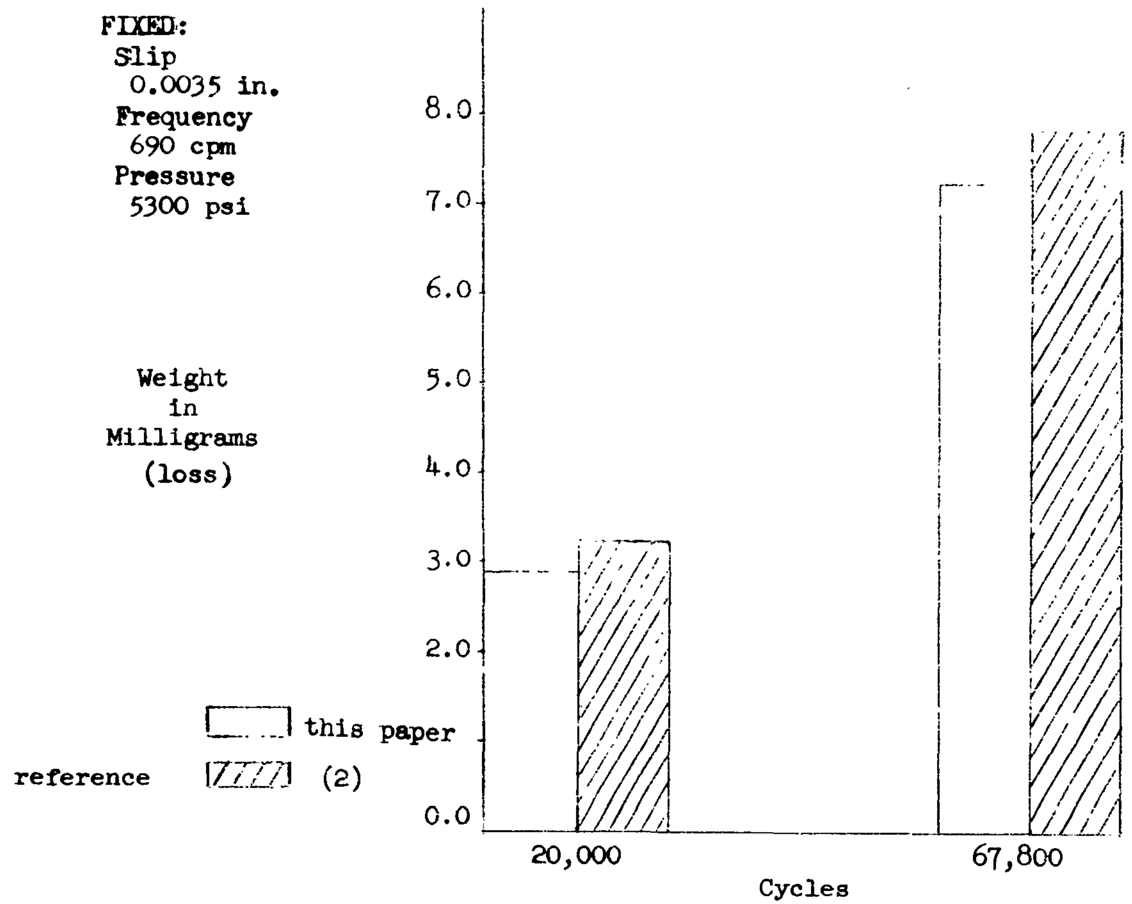
Each test point plotted on the following charts is an average value. The number of runs used in obtaining this average was not the same in all cases. Since this was an exploratory investigation, the major concern was to cover as wide an area as possible. The statistical case for some points is, therefore, somewhat weak. The bar graphs are encountered between a pair of specimens. The number of observations used in determining the magnitude of a given pair of bar graphs will be placed above the paired graphs. Whether or not a given specimen gained or lost weight was not dependent upon position of the individual specimen in the test machine. The transfer was apparently random in occurrence with regard to which of the specimens experiencing the gain.

In several of the following charts (5, 6, 8), damage to the specimen, as expressed by gain or loss, seems excessively high in comparison to damage observed at surrounding test points. It is my opinion that this is due to the effect of depth, height, or shape of the pits and or protrusions in acting as fatigue nuclei.

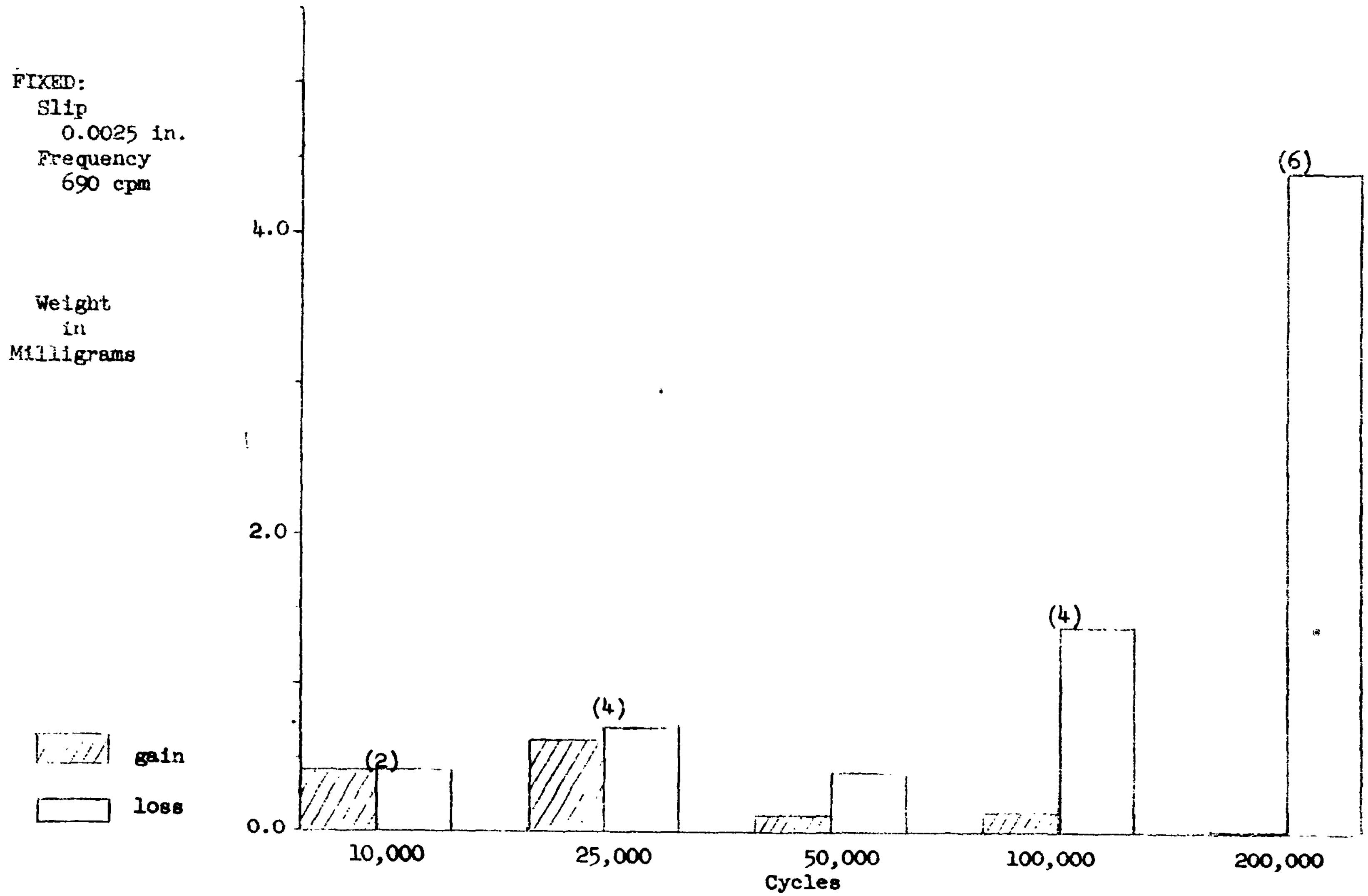
In all of the runs with lubricants, the adhesion type of wear (11, 12) seemed to predominate. This is in strong contrast to the large amount of abrasive type wear reported by Rabinowicz (13), Feng and

Rightmire (4), and Bailey and Godfrey (12). However, all of this work was done in the absence of lubricants. This predominance of adhesion type wear could be, in part, due to the small relative slip used in the experiments with the AMS 6260E steel. It is also possible that the wear debris was suspended in or carried away by the lubricant. This would, of course, limit any abrasive effects due to the debris.

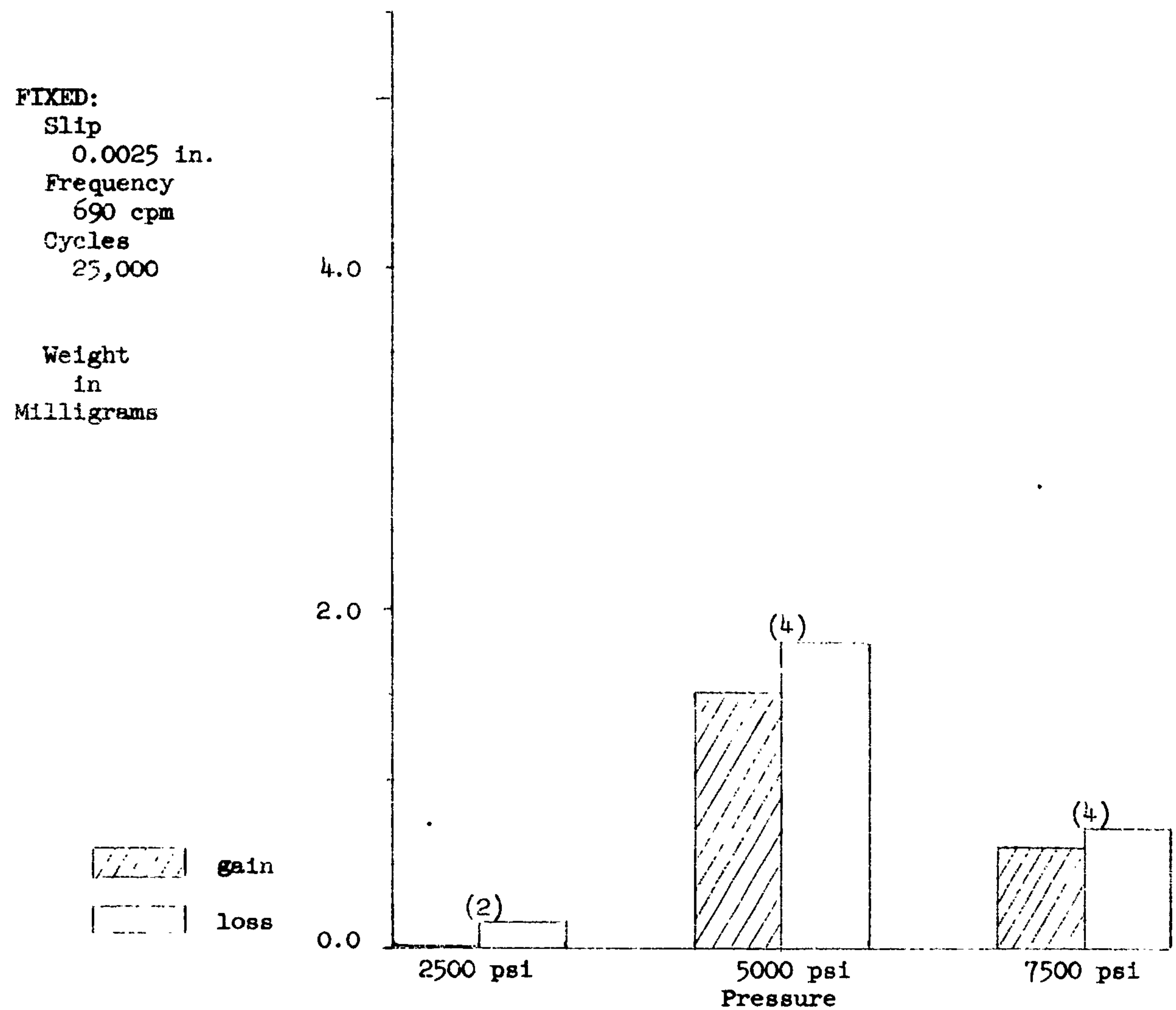
Several observations can be made regarding the data portrayed in Chart 2-9. First, that fretting in the presence of lubricants does not behave in the same manner as it does in the absence of them. In other words, the wear does not increase steadily with time. Secondly, the amount of metal gain between a pair of specimens tends to decrease with time. This would, in turn, suggest that more abrasive particles will be available to accelerate wear as the number of cycles is increased. In Charts 2 and 4, wear data is plotted for 200,000 cycles. Results at this particular point show a large weight loss (Chart 2) and a weight loss on the order of magnitude of the one obtained at 100,000 cycles (Chart 4). This would tend to support the previous hypothesis in the case of Chart 2. However, more tests are needed in this area before any conclusions can be reached.



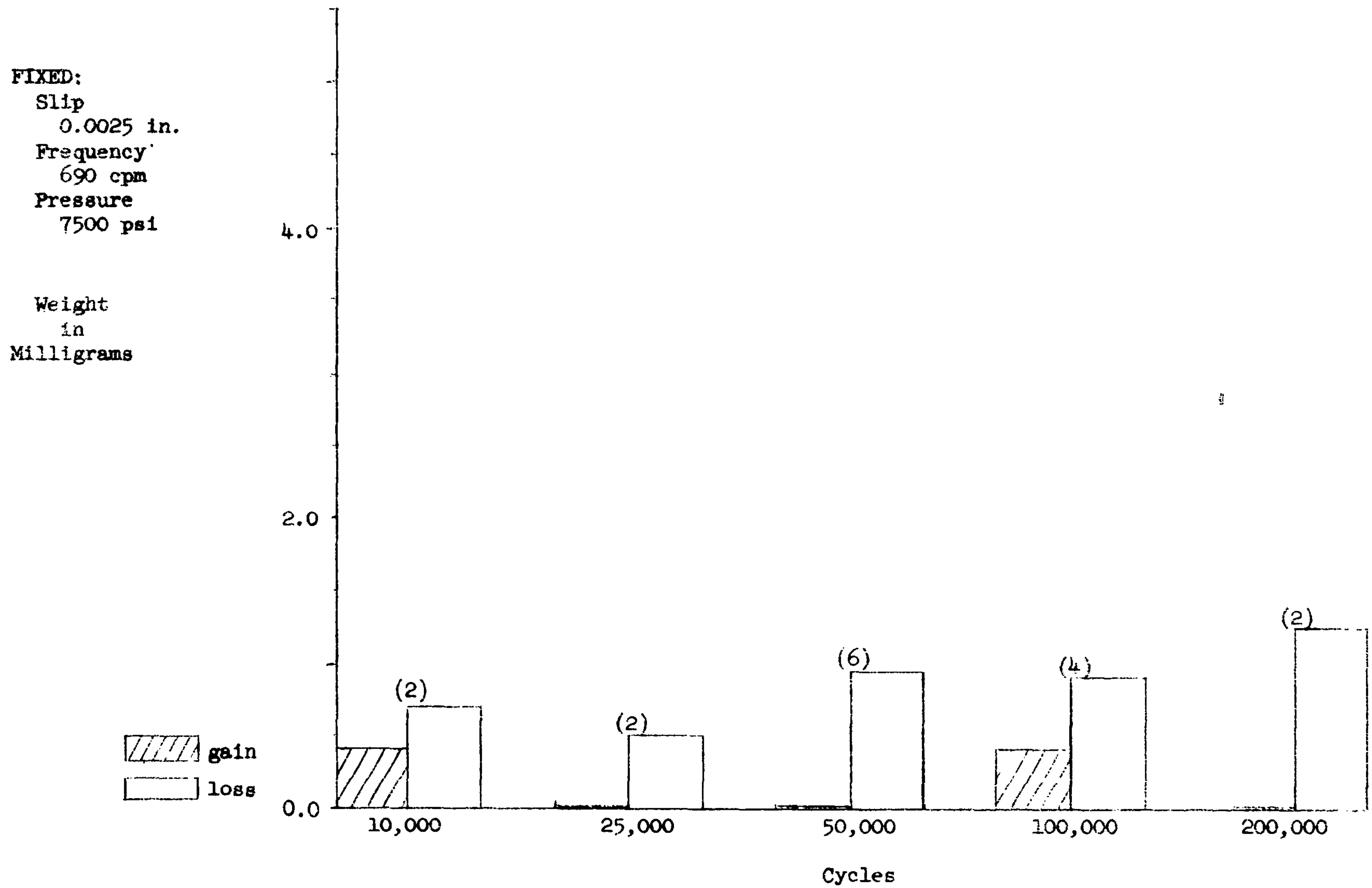
CORRELATION OF DATA
No Lubricant
Chart 1



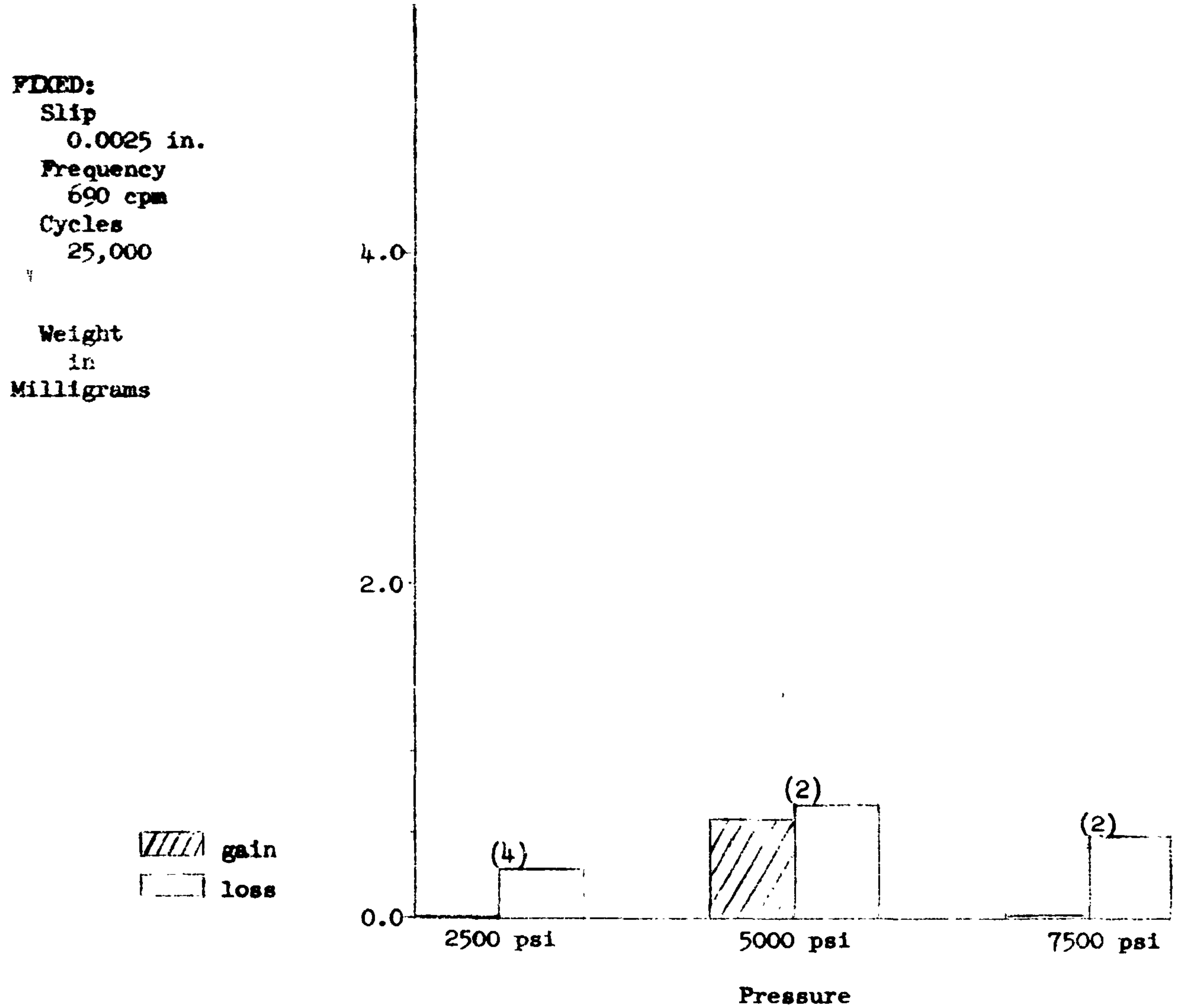
AVERAGE WEIGHT EXCHANGE
Molylube Sun Special
Chart 2



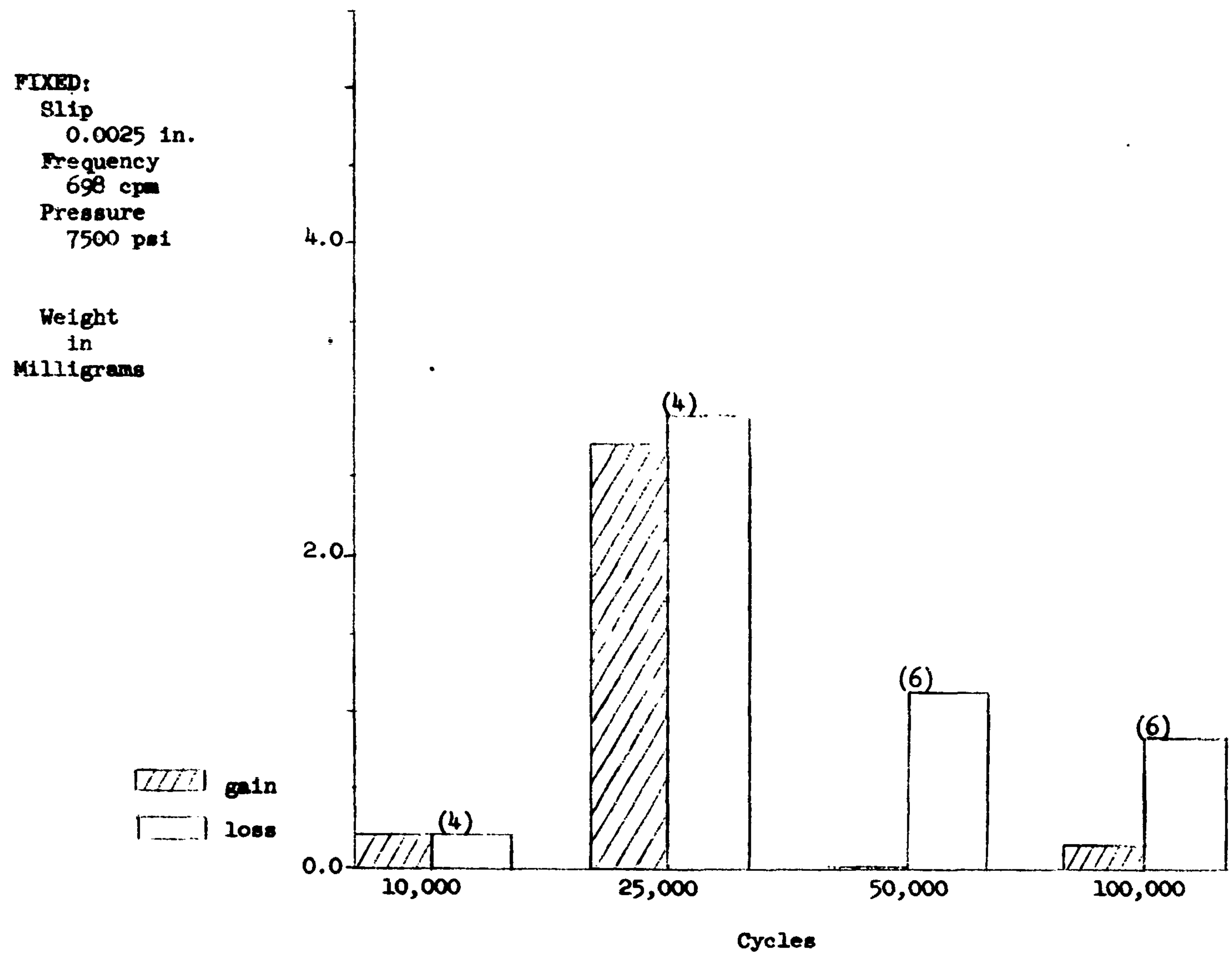
AVERAGE WEIGHT EXCHANGE
Molylube Sun Special
Chart 3



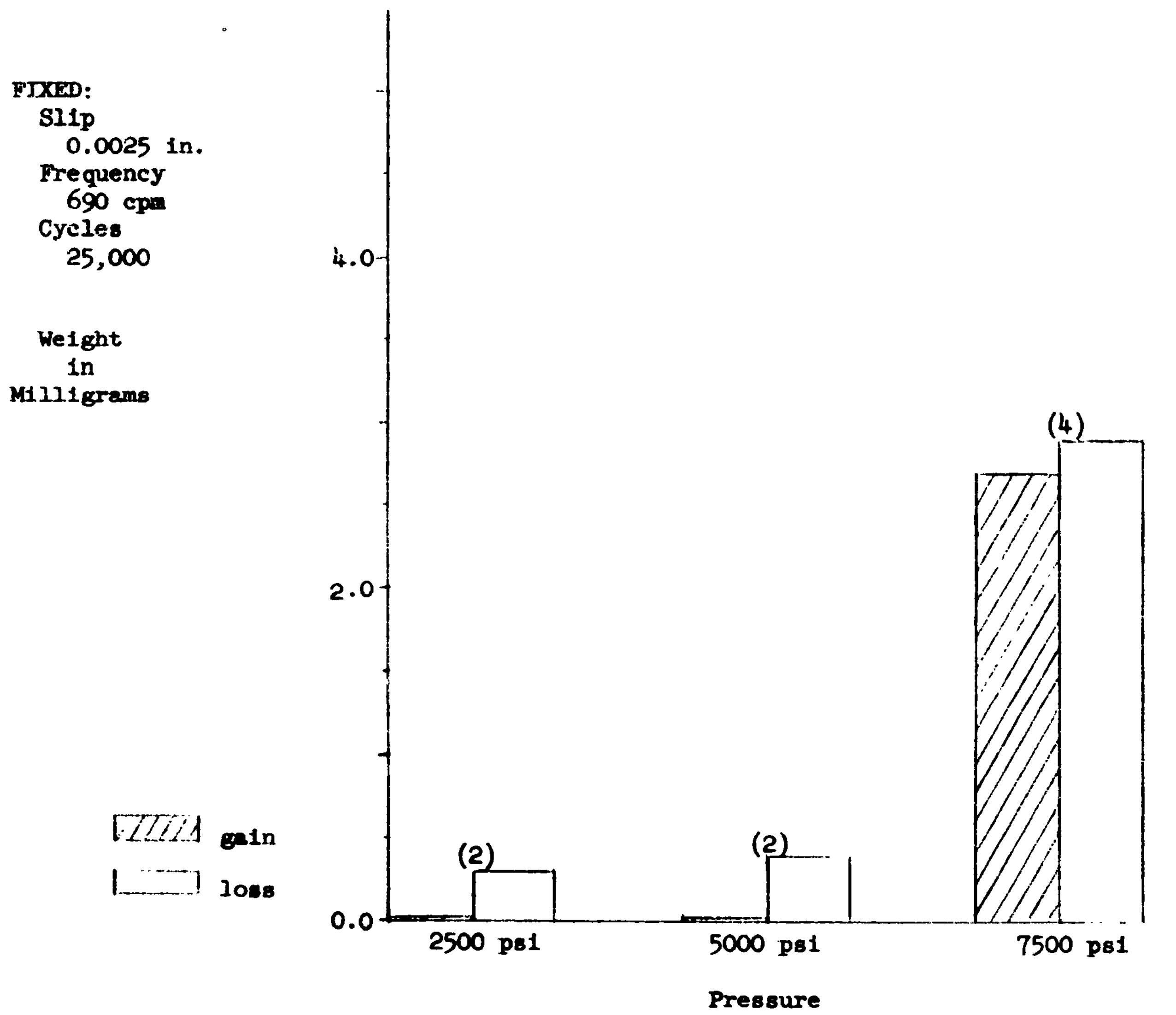
AVERAGE WEIGHT EXCHANGE
Pioneer 31
Chart 4



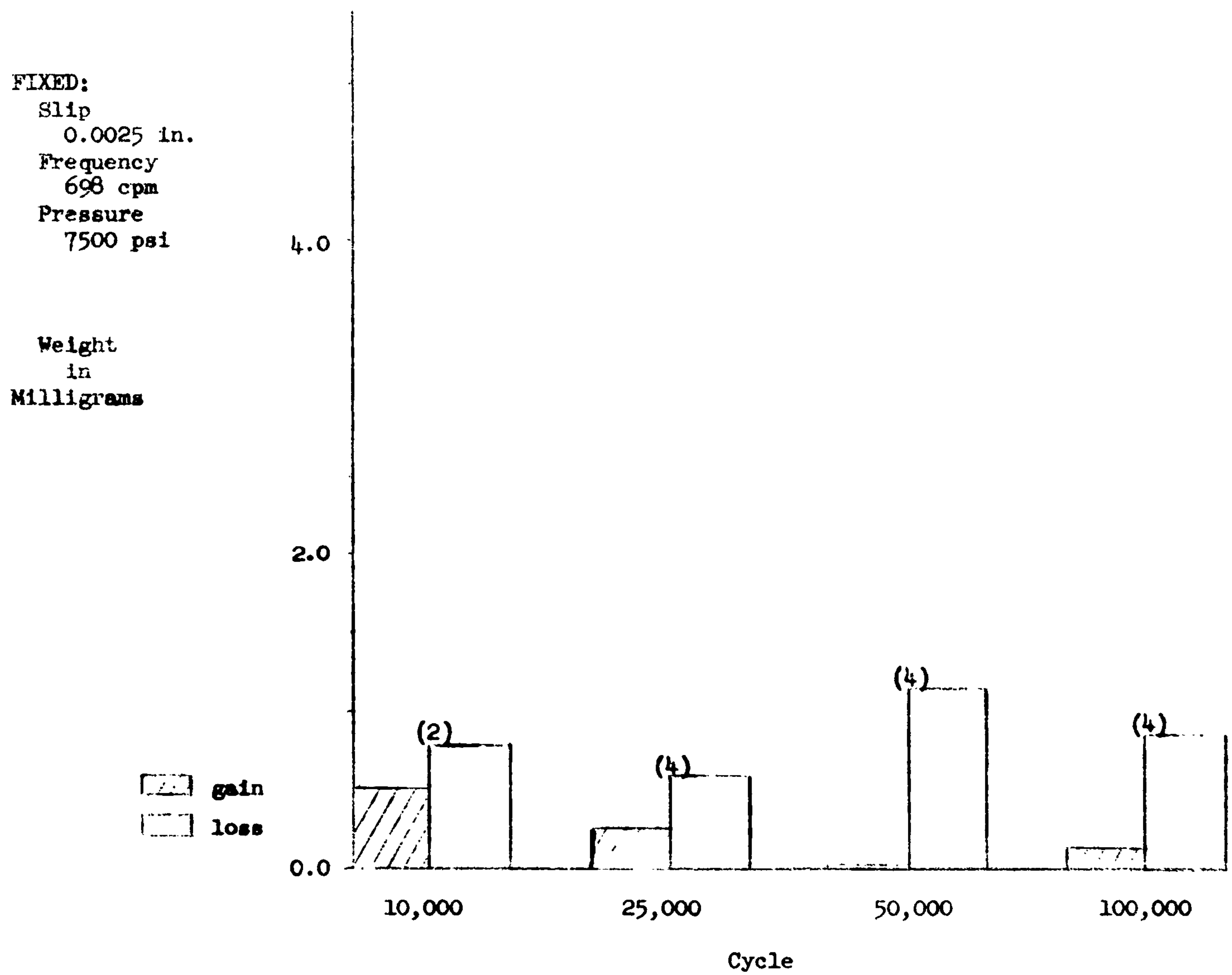
AVERAGE WEIGHT EXCHANGE
Pioneer 31
Chart 5



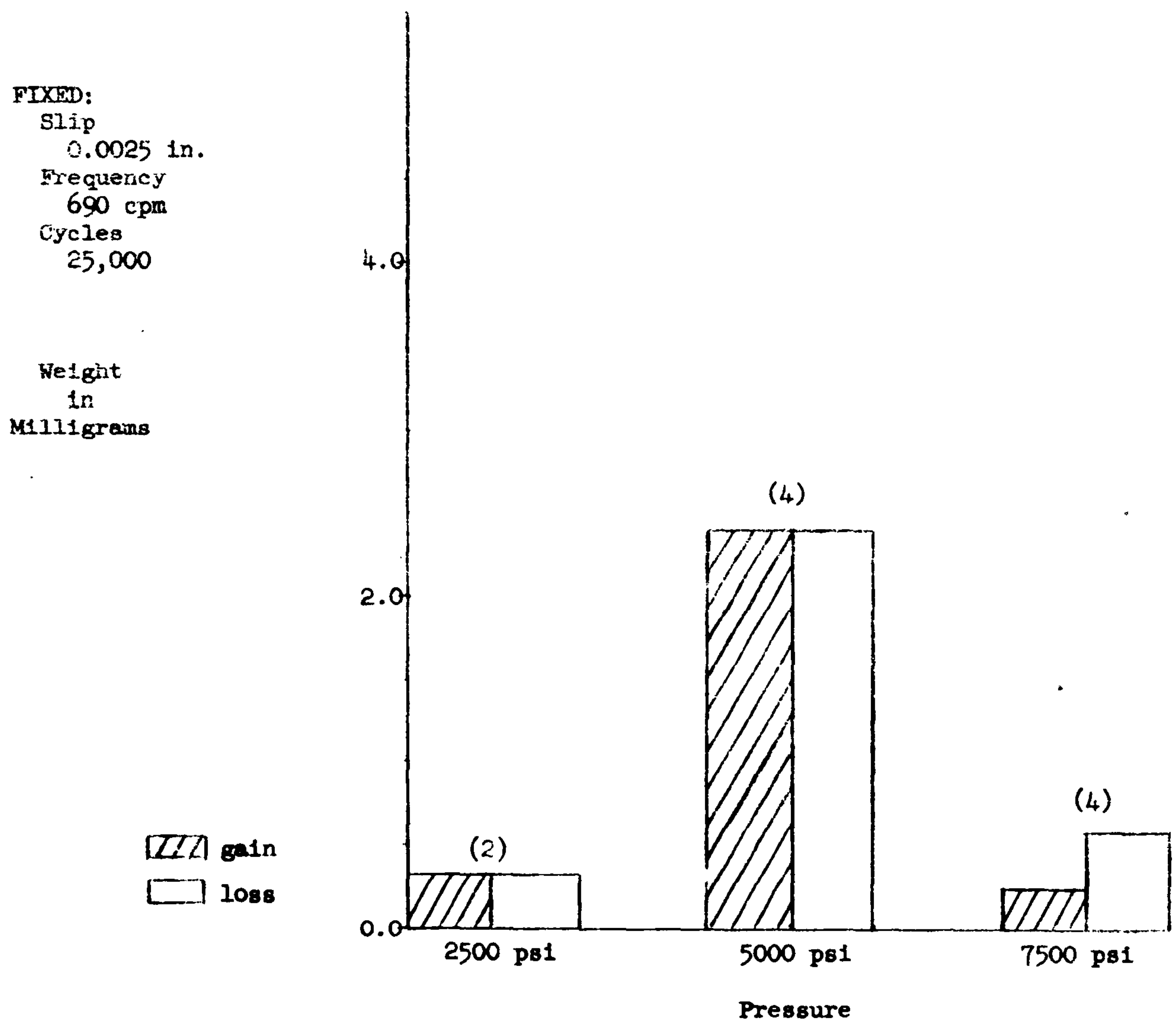
AVERAGE WEIGHT EXCHANGE
MIL-G-7118A & MIL-M-7866A
Chart 6



AVERAGE WEIGHT EXCHANGE
MIL-G-7118A & MIL-M-7866A
Chart 7



AVERAGE WEIGHT EXCHANGE
Plastilube III
Chart 8



AVERAGE WEIGHT EXCHANGE
Plastilube III
Chart 9

CHAPTER VI

CONCLUSIONS

A test machine has been designed and built to measure fretting damage quantitatively under controlled experimental conditions. Damage is measured by the weight loss of specimens subject to defined oscillatory slip. Load, frequency, and relative slip can be varied. Test results indicate that this machine has reproduced data obtained in (2).

Data were reported on the effects of four selected lubricants in reducing fretting of AMS 6260E steel against itself. It appears that fretting in the presence of lubricants does not behave in the same manner as it does in the absence of them. Adhesion type wear seems to predominate during the early stages of fretting with lubricants present. Some questions are posed as a result of this study.

1. Does increased pressure increase fretting damage?
2. In the adhesion wear process, to what extent is metal transferred back and forth between a pair of specimens?
3. Are the same wear rates associated with the various lubricants obtained with a larger relative slip?
4. What happens to the wear rates with a further increase in the number of cycles?
5. Does the lubricant affect the chemical corrosion properties of the wear debris, i.e., does it speed up or inhibit the reaction?

6. Is humidity an important parameter in wear of surfaces coated by lubricants?

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