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# LUBRICANT FRICTION AND DURABILITY TESTS UNDER SIMULATED WEAPON CONDITIONS

U.S. ARMY WEAPONS COMMAND

## TECHNICAL REPORT



**Bernard J. Bornong**

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DA 1W562604A607 AMS Code 552D.11.80700.02

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ABSTRACT

Lubricant friction and durability tests were carried out on four lubricants: VV-L-800A(PL-S), MIL-L-14107B(LAW), MIL-L-46000A(LSA), and MIL-L-46150(LSA-T). The tests were conducted on the USAWECOM Friction and Wear Tester, a reciprocating motion machine in which weapon action is simulated. In this test, AISI 4340 steel with a manganese phosphate finish was used. Test loads varied from 37 to 312 pounds or from 62 to 473 pounds per square inch. Dynamic friction coefficients obtained during operation at loads of 312 pounds were: PL-S, 0.15; LSA, 0.10; and LSA-T, 0.08. The LAW could not support the 312-pound load; its friction coefficient increased with increasing load. Lubricant durabilities were in the order LSA-T>LSA>PL-S>LAW. These results show a correlation with weapon tests.

## FOREWORD

The work described in this report was performed under DA Project 1W562604A607 and AMS Code 552D.11.80700.02, entitled "Components Applied Research." The title of the work unit was "Small Arms Simulator for Improved Lubricants Development." The work is continuing in FY71 under work unit entitled "Small Arms Components Motion-Simulator for Lubricants Development."

# CONTENTS

## BACKGROUND

The dynamic coefficient of friction is an important parameter that affects weapons dynamics. This coefficient has recently been treated as a viscous damping effect on the sliding motion of weapon components.[1] In this treatment, the frictional force is expressed as a function of the relative sliding velocities of the contacting surfaces. The viscous effect can be expected to hold for full-film or hydrodynamic lubrication. However, for thin or mixed film lubrication often encountered in weapons, the situation is more complex.

The complexity of friction phenomena can be illustrated by use of the following partial list of factors that affect the lubrication of rubbing surfaces:

1. Contact geometry (area and shape)

2. Surface roughness

3. Relative velocities

4. Loading conditions

5. Temperature

6. Dimensional tolerances (clearances)

7. Relative acceleration

8. Physical-chemical lubricant properties (viscosity, adsorption, transition temperatures of surface films, chemical reactions, etc.)

9. Physical-chemical properties of contacting surfaces (adhesion, hardness, mutual solubility, elasticity, shear strength, tensile strength, compressibility, oxide or corrosion film formation, etc.)

The mechanisms by which these factors affect friction are too complex for discussion in a limited space. These mechanisms, however, have been fully treated elswehere.[2,3,4] Changes in friction forces are not the only result of the interplay of the factors listed. These factors also affect, in various ways, the wear of the contacting surfaces.

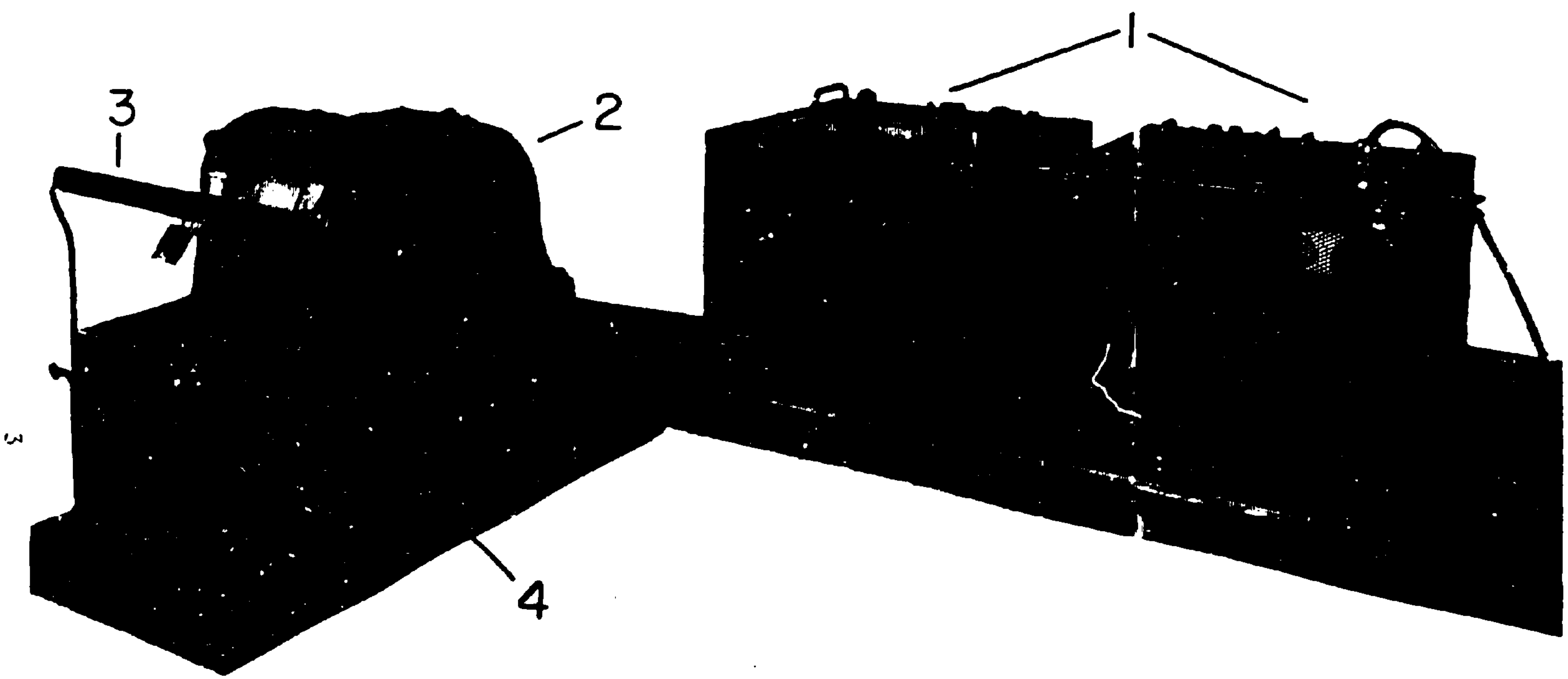
Wear is generally classified as mild or severe. In mild wear, the surfaces become polished and the wear rate is slow.

In severe wear, the surfaces are damaged by galling, chafing, and scoring. Bowden and Tabor[5] list the mechanisms that may be involved in wear. These mechanisms include adhesion and shearing of interfacial junctions, alloy formation at the interface, fatiguing of transferred fragments, oxidation of freshly exposed surfaces, abrasion by oxidized wear fragments, and chemical corrosion.

The multitude of parameters involved in lubrication makes uncertain the prediction of lubricant behavior based on laboratory tests. Tests are often conducted under simulated conditions to obtain data to remedy some of these uncertainties. The aim of this research program is to provide test conditions and equipment to conduct lubricant tests under simulated weapon conditions. The lubricant tests, reported here, are part of the initial effort toward this end. These experiments were conducted on a friction and wear tester that was built at Springfield Armory,[6] and is now called the USAWECOM Friction and Wear Tester.[7] An overall view of the tester is shown in Figure 1. A closeup view of the friction and wear specimens, in place for testing, is shown in Figure 2.

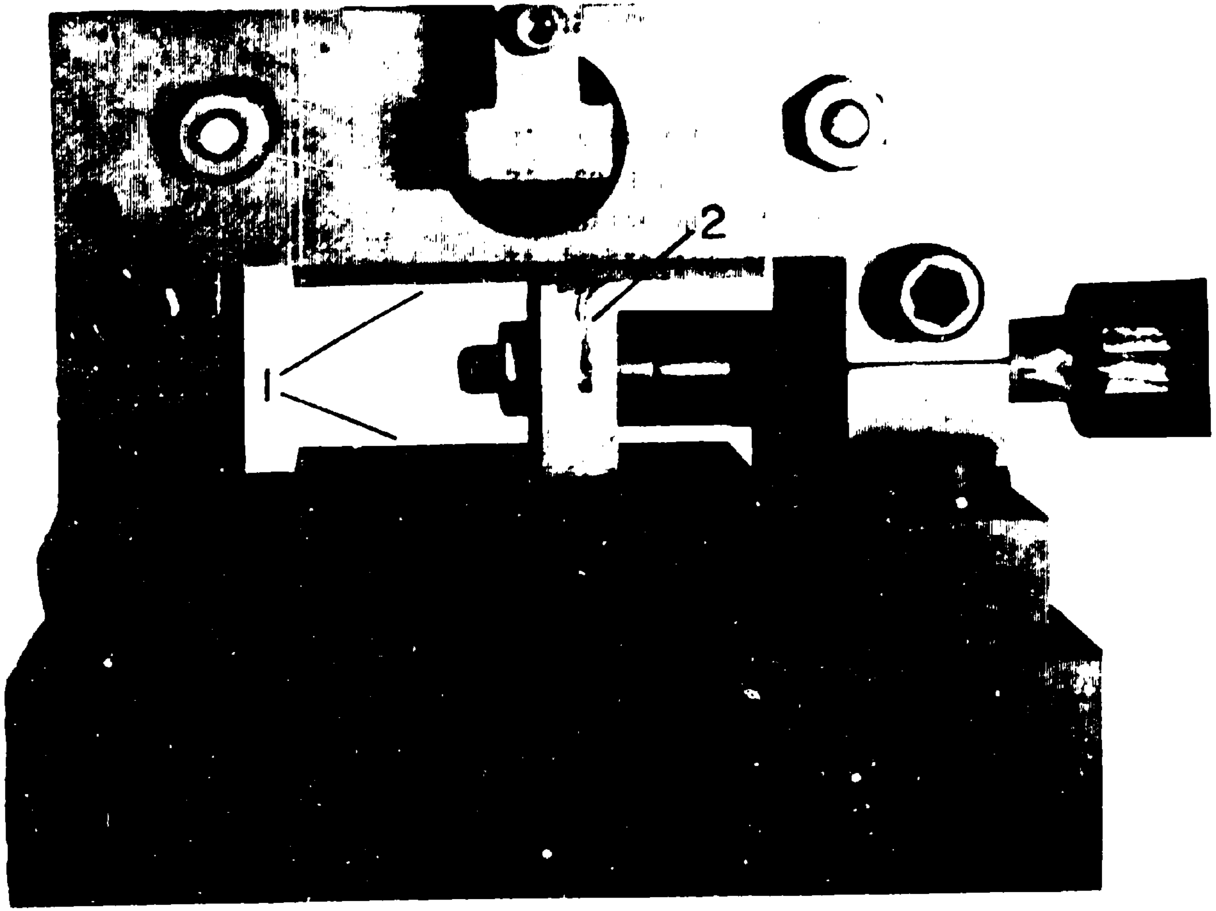
## PROCEDURE

The general procedure for use of the USAWECOM Friction and Wear Tester was described by George.[6,8] Two slight modifications were made in the machine and test specimens for these tests. First, a clevis and pin and a screw clamp were added to hold the weights more securely. Second, the dimensions of the reciprocating test specimen were changed from 1-1/4 by 1-1/4 by 1/2 inch to 7/8 by 7/8 by 1-1/4 inch. A 1/32-inch radius was ground on each edge of the square faces of these specimens, which were used as the contacting surfaces for the tests. The area of the contacting surface was, therefore, 0.66 square inch. These changes were made with the expectation that the alignment of the test specimens would be facilitated and that the noise level of the machine would be reduced. The test specimens were made of AISI 4340 steel. The steel blocks were roughed out, then heat-treated and quenched to a Rockwell C hardness of 38-43. They were then surface-ground to a 32 microinch finish. The specimens were then grit-blasted with 80 mesh steel grit and given a manganese-phosphate coating (according to Specification MIL-P-16232, Type M) with no supplementary treatment. These specimens were stored in a controlled room at 40 ± 10 per cent relative humidity and 73° ± 2°F until they were used, from one to three weeks later. The lubricant friction and




1. Amplifier and Recorder for Strain Gauge
2. Drive Motor, Variable Speed
3. Load Lever Arm
4. Test Area

FIGURE 1 USAWECOM FRICTION AND WEAR TESTER




1. Upper and Lower Stationary Test Blocks or Specimens
2. Reciprocating Test Block

FIGURE 2 TEST AREA OF USAWECOM FRICTION AND WEAR TESTER wear tests were conducted in an uncontrolled laboratory room at an ambient temperature ranging from 78° to 85°F. The general procedure for the tests is described in the following paragraphs.

The friction and wear tester was set to operate with a 1.5-inch stroke at 600 cycles per minute. A correction factor was determined for the force of acceleration of the reciprocating test block to be applied to subsequent frictional force measurements. The test specimens were assembled in the machine and aligned as well as possible. For final alignment, the test blocks were slightly separated and the line of light between them was observed. For changes in alignment, shims were inserted and the rollers were adjusted on the machine.

The lubricant was applied to the test surfaces after the specimens were aligned. The upper, movable specimen was first removed from the machine. Then both the upper and the lower test surfaces were coated with a thin film of lubricant applied with a gun patch. Two to three drops of lubricant were placed in the center of each upper and lower specimen. The upper test block was then replaced and a final check made of alignment, which was somewhat obscured by the lubricant. The weight holder was put in place. The chart of the recorder, which had been warming up for the prescribed period, was turned on and the tester turned over by hand for 10-12 cycles. This initial hand operation was done to work the lubricant into the test surfaces and to record the static coefficient of friction. The drive motor was then turned on with no weights in the holder. A 5-pound weight was then added after every 30 seconds until 25 pounds were added. The initial load was 37 pounds; the final total load, applied by means of the load arm with an 11:1 mechanical advantage, was 312 pounds. The machine was allowed to run with the maximum load on the test blocks until the coefficient of friction increased significantly or until galling and seizing of the test specimens occurred. These events indicated failure of the lubricant. The endurance time of the lubricant, or durability, was taken as the time interval from initial application of the 312-pound load to failure.

Data obtained from these tests are as follows: (1) static friction coefficient at 37-pound load for the dry phosphate surfaces; (2) static friction coefficients for lubricated surfaces at 37-pound load; (3) dynamic friction coefficients at 37-, 92-, 147-, 202-, 257-, and 312-pound loads (determined 30 seconds after application of each load); (4) dynamic friction coefficients during operation of machine at maximum 312-pound load; and (5) lubricant durability of four weapon lubricants.

The lubricants used in these tests were samples obtained from qualified suppliers of the following materials:

1. VV-L-800A(PL-S).[9] This is a lubricant with a mineral oil base, containing corrosion inhibitors, an oxidation inhibitor, surfactants, and polymeric pour-point depressant additives.

2. MIL-L-14107B(LAW).[10] This is a lubricant with a tetrakis(2-ethylhexyl) silicate base, containing corrosion, oxidation, and hydrolysis inhibitors.

3. MIL-L-46000A(LSA).[11] This is a semifluid lubricant with a diester (Bis(2-ethylhexyl)sebacate) base, containing lithium stearate as a thickener, barium dinonyl-naphthalene sulfonate as a corrosion inhibitor, 2,6-di-tertiary butyl-p-cresol as an oxidation inhibitor, and diisopropyl phosphite as an antiwear agent.

4. MIL-L-46150(LSA-T).[12] This is a lubricant that consists of MIL-L-46000 lubricant with polytetrafluoroethylene molding powder added for improved lubrication.

## RESULTS AND DISCUSSION

The average hardness of the test specimens was determined to be 42.5 ± 0.8 (95 per cent confidence) Rockwell C.

The static coefficient of friction obtained on one set of specimens for the dry manganese phosphate coating was 0.85 at the 37-pound load. The remaining specimens were saved for lubricated tests. George[6] obtained a value of 0.876 for the static coefficient on the same type of surface at loads up to 197.1 pounds and 0.86 at 32.1 pounds.

Static coefficients of friction for lubricated manganese phosphate surfaces at 37-pound load are shown in Table I.

## TABLE I

## STATIC FRICTION COEFFICIENTS

| Lubricant | Static Friction Coefficient | Number of Measurements | Standard Deviation |
|---|---|---|---|
| VV-L-800A | 0.22 | 8 | ±0.03 |
| MIL-L-14107B | 0.20 | 2 | ±0.01 |
| MIL-L-46000A | 0.19 | 5 | ±0.03 |
| MIL-L-46150 | 0.18 | 6 | ±0.01 |

These results indicate that no significant difference is present in static friction coefficients between the four lubricants tested. The coefficients are higher than similar data reported by George (0.13 to 0.15).[4,6] The differences may be explained by the greater surface roughness, 95-125 microinches root mean square, in the present experiments compared with 63 microinches reported by George.

Dynamic friction coefficients obtained in this series of tests are shown in Table II.

TABLE II

DYNAMIC FRICTION COEFFICIENTS ($\mu$)

| Lubricant | | Load (lb.) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 37 | 92 | 147 | 202 | 257 | 312 |
| VV-L-800A | $\mu$*= | 0.16 | 0.17 | 0.23 | 0.18 | 0.16 | 0.18 |
| MIL-L-14107B | $\mu$ = | 0.16 | 0.17 | 0.18 | 0.20 | 0.32 | >0.6 |
| MIL-L-46000A | $\mu$ = | 0.13 | 0.13 | 0.17 | 0.16 | 0.15 | 0.13 |
| MIL-L-46150 | $\mu$ = | 0.18 | 0.16 | 0.18 | 0.16 | 0.13 | 0.12 |

*Each coefficient is an average of 2-5 measurements. Average standard deviation is ±0.03.

The coefficients given in Table II show a maximum, in the midrange of loads, from 147 to 202 pounds except for MIL-L-14107B. A maximum was also found by George,[6] who attributed it to a misalignment in the test machine at these loads. This explanation seems reasonable because the maximum cannot be attributed to a particular lubricant in the present tests.

In the present tests, once the 312-pound load was applied, the friction coefficient continued to decrease, except for the MIL-L-14107B, to a minimum. Then, the coefficient gradually increased until the limit of durability was reached; at which time, the friction suddenly increased to high values, and galling or scoring often occurred. The average minimum friction coefficients were as follows: for VV-L-800A, 0.15; for MIL-L-46000A, 0.10; and for MIL-L-46150, 0.08. These minimum coefficients occurred approximately halfway through the durability period.

The lubricant durabilities are shown in Table III. Averages are not given because of inconsistencies in some of the data. These durability results were not reproducible, probably, because slight misalignments of the test blocks cause wide variations in unit loading. Nevertheless, the results show what can happen when weapon parts are poorly assembled, or when parts become misaligned by wear and buildup of contamination.

TABLE III

LUBRICANT DURABILITY AT 312-POUND LOAD

| Lubricant | Time to Failure, Minutes | Surface Condition at Failure |
|---|---|---|
| VV-L-800A | 1.0 | Galled lightly |
| | 1.0 | Galled |
| | 0.2 | Galled lightly |
| | 0.2* | Polished |
| | 0.5 | Polished, light score |
| MIL-L-14107B | 0.0 | Galled |
| | 0.0* | Galled |
| MIL-L-46000A | 8.9 | Galled |
| | 13.0* | Galled |
| | 2.9 | Galled |
| | 11.5* | Galled |
| | 5.7 | Polished, light score |
| MIL-L-46150 | 22.5* | Polished |
| | 29.6* | Galled lightly |
| | 42.0* | Polished |
| | 7.6** | Galled |
| | 0.0** | Galled |
| | 0.0** | Galled |

*Best alignment of test blocks as indicated by uniformity of wear pattern.

**Phosphate coating crushed by light impacts during assembly and alignment of test specimens. Galling occurred in these damaged areas.

The results in Table III indicate that the LSA-T lubricant is the most durable when the rubbing surfaces are well aligned and undamaged before loading. This lubricant showed the least tendency to gall; the test surfaces were generally smooth and showed the least damage at the end of the tests. The MIL-L-14107B lubricant could not support the 312-pound test load, as indicated by the friction coefficients in Table II and durability data in Table III.

The data reported here show different orders of durability for the PL-S and LAW, and for the LSA and LSA-T than for those that were obtained in an earlier durability test on the Falex lubricant tester.[7] However, test specimen materials and surfaces, type of motion and loading conditions, and lubricant suppliers or samples were different in these earlier tests from those used here; the discrepancies can be explained by any one of the factors listed.

A general correlation exists between results obtained here and results of weapon tests. LSA was superior to VV-L-800 in overall performance in tests on the M16 rifle.[13] The LSA-T has been proved to be superior to LSA and other lubricants recently tested on the Minigun.[14] The MIL-L-14107 lubricant showed poor lubricating qualities in these tests.

## CONCLUSIONS AND RECOMMENDATIONS

Results of these simulated tests are correlative, in a general way, with those of weapon tests of the same lubricants. A continuation of these experiments is planned involving other current and experimental lubricants, and with metals and surface finishes typical of those used in small arms weapons.

Slight misalignments in the test specimens cause wide variations in lubricant durability results. However, these misalignments cause only slight changes in friction coefficients. The present method of aligning the specimens before lubrication sometimes results in surface damage. A light lubricant film will be used during alignment in future tests. Better specimen alignment does not appear possible without major changes in the present test apparatus. This problem will be corrected in the new weapon components motion-simulator now in procurement.[7]

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13. ABSTRACT

Lubricant friction and durability tests were carried out on four lubricants: VV-L-800A(PL-S), MIL-L-14107B(LAW), MIL-L-46000A(LSA), and MIL-L-46150(LSA-T). The tests were conducted on the USAWECOM Friction and Wear Tester, a reciprocating motion machine in which weapon action is simulated. In this test, AISI 4340 steel with a manganese phosphate finish was used. Test loads varied from 37 to 312 pounds or from 62 to 473 pounds per square inch. Dynamic friction coefficients obtained during operation at loads of 312 pounds were: PL-S, 0.15; LSA, 0.10; and LSA-T, 0.08. The LAW could not support the 312-pound load; its friction coefficient increased with increasing load. Lubricant durabilities were in the order LSA-T>LSA>PL-S>LAW. These results show a correlation with weapon tests. (U) (Author)

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| 2. Lubrication | | | | | | |
| 3. Wear | | | | | | |
| 4. Small arms weapons | | | | | | |

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