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NO. SA-TR18-1089

DATE 17 September 1

FRictional AND WEAR CHARACTERISTICS OF VARIOUS COATINGS USED ()
SMALL CALIBER WEAPON COMPONENTS

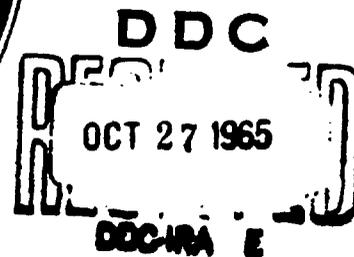
Technical Report

Author

George, M. A.

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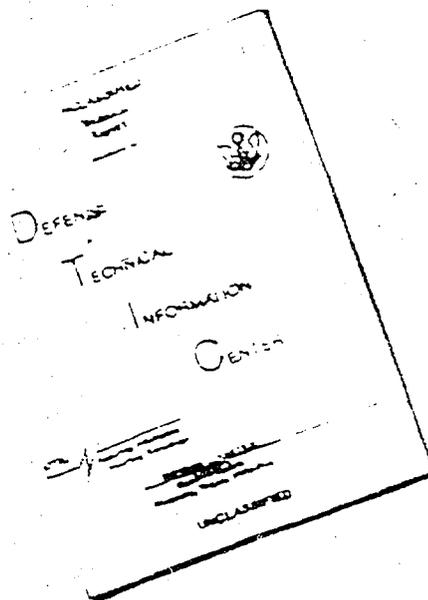
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REPORT: SA-TR18-1089

DATE: 17 September 1965

AMCMS CODE: 5016.11.84400.02

FRICTIONAL AND WEAR CHARACTERISTICS OF VARIOUS COATINGS USED ON
SMALL CALIBER WEAPON COMPONENTS

Technical Report

George, M. A.

PROJECT TITLE: In-House Laboratory Initiated Research and Development
FY64

PROJ: M1-4-50020-01-M1-M6

Preparing Agency: Springfield Armory, Springfield, Massachusetts

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ABSTRACT

Friction and wear studies, in which Springfield Armory friction and wear machine was used, were continued. Information relating to the frictional and wear properties of coatings was obtained under simulated weapon conditions. Various coatings such as phosphate, chromium plate, and hard-anodized aluminum were evaluated. The rough porous coatings such as phosphated steel and hard-anodized aluminum generally had high coefficients of friction when unlubricated, but exhibited good wear resistance when lubricated. Chromium plate, when unlubricated, had a lower coefficient of friction than steel of equal surface roughness. Metallic surfaces such as chromium plate and hardened steel had limited antigalling properties. Procedure is given, and results are discussed.

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SUBJECT

Investigation of Frictional and Wear Characteristics of Various Coatings Used on Small Caliber Weapon Components.

OBJECTIVE

To obtain data on the frictional and wear properties of various coatings used in small caliber weapon systems.

SUMMARY OF CONCLUSIONS

1. Chromium plate sliding on chromium plate, with no lubrication, has a lower coefficient of friction when compared to dry steel on steel of equal surface roughness.
2. Hard anodic coatings, with no lubrication, have a relatively high coefficient of friction (.55), probably because of the rough nature of the surface.
3. Phosphate coatings appear to be beneficial in reducing the coefficient of friction when they are dry and in contact with a smooth surface.
4. Unprotected steel surfaces have poor wear resistance, especially in the prevention of galling.
5. The coefficient of friction for well-lubricated surfaces is primarily dependent upon the nature of the lubricant.
6. Rough porous surfaces, such as those produced by phosphating and hard anodizing, have better oil-retaining capabilities than smooth metallic surfaces and, consequently, exhibit better wear resistance, when lubricated, under high loads.

RECOMMENDATIONS

1. The use of phosphate coatings should be continued on small caliber weapon components since the coatings, when properly lubricated, give adequate coefficients of friction and excellent wear resistance.
2. Chromium plate, when in contact with itself at high loads, exhibits some galling tendencies and its use should be avoided.
3. Endurance tests should be conducted on the various combinations of coatings to determine the best coating for contact with chromium plate and other coatings at high loads for increased wear resistance.
4. In instances where very low coefficients of friction are required in weapon systems (<.1), a lubricant better than MIL-L-644 oil should be used.
5. Friction tests should be conducted on other oils, greases, and dry

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RECOMMENDATIONS - Continued

film lubricants to determine lubricants that will provide lower coeff of friction than MIL-L-644 oil.

6. Hard-anodized aluminum usually galls or seizes after the coat completely worn away; thus, the use of thick, hard-anodized aluminum should be continued.

1. INTRODUCTION

Friction and wear studies were continued at the Springfield Armory. Previous work reported in SA-TR18-1084¹ was expanded to include various coatings used on small caliber weapons today. The purpose of this investigation was to obtain information relating to the frictional and wear properties of coatings under simulated weapon conditions.

A friction and wear machine designed and built at Springfield Armory was employed in the investigation. The machine is unique in that it offers a reciprocating type of motion while providing a plane-to-plane type of contact between specimens during the sliding action. The machine is designed to operate at speeds from 600 to 2000 rpm, under loads from 32.1 pounds to 417.1 pounds, and strokes up to approximately 2.5 inches.

The previous study involved the factors influencing the friction of phosphate coatings. This report includes the study of the frictional and wear properties of various coatings such as chromium plate and hard-anodized aluminum.

2. PROCEDURE

a. Preparation of Test Specimens

(1) Machining.

The 4340 steel blocks used in the testing of chromium plate and phosphate coating were heat-treated and quenched to a final hardness of Rockwell C 45-50. The 6061-T6 aluminum blocks used in the testing of the hard-anodized coating had hardnesses of Brinell 83 to 86. Final surface grinding produced surfaces that were parallel within .0002 inch and gave surface roughness values of approximately six microinches (rms) as measured on a profilometer.

(2) Surface Preparation and Metal Finishing

(a) Chromium Specimens.

Prior to plating, the steel specimens were alkaline-cleaned and given a 15-second reverse etch. The plating was done in a standard chromium bath of 250 grams per liter at a temperature of 130°F. An average thickness of .0005 inch was obtained in 30 minutes. The throwing power of chromium plating was considered in that an anode of the same size as the wearing area of the large block was used. Some buildup at the edges occurred;

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2. PROCEDURE - Continued

however, it was not important since it was not in with the smaller block. The plating of the smaller required use of robbers around the edges. Preliminary friction testing revealed that the chromium-plated were not devoid of buildup in some areas. For this the specimens were polished after plating, producing surfaces with roughness readings of three to four inches (rms).

(b) Steel Specimens.

Preliminary testing of the steel specimens revealed galling tendencies at the minimum load of the machine. This problem was corrected to some degree by polishing samples. The surface roughness values prior to test were three to four microinches (rms).

(c) Phosphated Specimens

Prior to phosphating, the steel specimens were abrasively blasted with steel grit (Number 120). The blocks were then phosphated for 30 minutes at 205°F. in a standard manganese phosphate solution with the following composition: total acid 55-65 points, free acid 10-11 points, an .1 to .3 points. Prior to phosphating, the surface roughness was 63 microinches (rms); it was not significantly changed after the phosphating.

(d) Hard-Anodized Specimens.

The aluminum specimens were hard-anodized according to the MHC process. The surface preparation consisted of a blast. The 15 per cent sulfuric acid electrolyte was at 28°F. and the process was accomplished at a current of .2 amps per square inch. An average thickness of .001 inch was obtained after one hour. The surface roughness of the hard-anodized specimens was 45 to 55 microinches (rms).

b. Friction Testing

(1) Static Testing.

A simulated static coefficient was obtained by hand-operation of the movable block at a very slow rate. The maximum deflection on the recorder was considered to be the static friction. The load was increased by adding weights to the weight carriage.

2. PROCEDURE - Continued

in one-pound increments, up to 10 pounds. The friction force obtained for each load was taken when the recorder deflection had reached a constant value for each cycle of movement. This was considered the break-in point for the coating.

A dry and a lubricated trial were conducted for each coating. All oil-coated coatings were lubricated with MIL-L-644 oil. The coatings had a slight excess of oil since the blocks were aligned in the dry state and lubrication followed correct alignment. Hydrodynamic lubrication was probably approached during the static testing.

(2) Dynamic Testing.

Dynamic testing of the dry coatings was not possible. The high friction forces and vibrations from the motor tended to tilt the blocks out of position and galling occurred. Dynamic tests were run on the lubricated coatings. Loads were increased by applying weights in one-pound increments to the weight tray. The break-in point for each load usually occurred within 10 or 15 seconds. The maximum deflection, representing the maximum friction force for one cycle of movement, was taken at the break-in point, where the maximum deflections had reached a steady value.

Dynamic endurance tests were conducted for the following specimens: steel-on-steel, chromium-on-chromium, hard-anodized aluminum on hard-anodized aluminum, and phosphate-on-phosphate. The blocks were well-lubricated prior to testing and a constant load was applied. Initial testing under a load of 87.1 pounds disclosed that only the steel-on-steel blocks would fail within a period of one hour. It was decided to increase the load to 307.1 pounds to get an earlier indication of the relative wear resistance of the various materials.

c. Calculation of the Coefficient of Friction

The coefficient of friction is determined by dividing the friction force by the normal force. The normal force equals the load applied to the blocks. The load consists of two parts: the minimum load with no weights attached, and the additional load developed by the attachment of weights. The minimum load consisted of the weight of the upper friction block attached to its holder, and the reaction of the weight of the lever arm and weight tray applied at the point where friction occurs. This minimum load was determined to be 32.1 pounds.

The lever arm acts as a second-class lever with a mechanical advantage

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of 11 to one. Thus, an increase of one pound on the weight tray result an increase in the load of 11 pounds.

The friction force is calculated from strain measurements obtain the use of strain gages attached to the reciprocating rod, which drive moving friction block. The strain gages were calibrated under tensile compressive loads to give one millimeter recorder deflection for a 11/ pound load.

An analysis of the design of the friction machine revealed that maximum deflection should be divided by a factor of four to give the friction force between the surfaces of the specimen blocks. The maximum deflection for one cycle of movement represents two frictional forces as as the total of the frictional forces acting in compression and tension. The two friction forces are developed at the upper and lower surfaces middle block where contact is made with the two stationary blocks. This differs by the weight of the middle block at the two contact points, but this difference was neglected since the middle block weighs only 1/4 pound. The following equation represents the method of calculating the static coefficient of friction:

$$\mu_s = \frac{D^{5/4}}{32.1 + 11W}$$

μ_s = Static coefficient of friction

D = Maximum recorder deflection

W = Load applied to weight tray

In reciprocating motion, forces due to acceleration or inertial are present because velocity is not constant. The rotary motion of the motor is changed to rectilinear motion by a crank and connecting rod mechanism. The force due to acceleration was determined easily when the machine was operated with the middle block only and the friction forces were eliminated. The acceleration forces were dependent upon the length of stroke and the number of revolutions per minute of the motor. A short stroke and a low speed were used so that the effect of acceleration could be minimized. The values selected for all dynamic tests were a one-inch stroke and 600 rpm. Under these conditions, the maximum recorder deflection for one cycle of movement was found to be only one millimeter.

The following equation represents the method of calculating the dynamic coefficient of friction:

$$\mu_D = \frac{(D-1)^{5/4}}{32.1 + 11W}$$

μ_D = Dynamic coefficient of friction

D = Maximum recorder deflection

W = Load applied to weight tray

When high friction forces were present, it was necessary to change the attenuator on the amplifier from the 1 scale to the 4 scale. This, in essence, cut the deflection fourfold and increased the calibration factor to 20 pounds per millimeter.

3. RESULTS AND DISCUSSION

a. Wear Resistance

Wear can be defined as the deterioration caused by use and can usually be classified into two main categories: normal wear and destructive wear. Normal wear refers to the wear that is to be expected, i.e., the loss of material from the working surfaces when two materials are in contact during a sliding action.² Normal wear can be beneficial at times, since the surface roughness can be improved by the leveling of local projections on the surfaces.

Destructive wear refers to the transfer of metal from one surface to another by welding under sliding conditions. The welding is caused by great localized pressure in which sufficient temperature is generated to weld the surfaces together. Terms such as galling, scuffing, scratching, and scoring usually are used to express varying degrees of damage by welding.³

In this investigation, wear resistance will refer to the ability to prevent galling and other types of severe surface damage. A criterion in this investigation for good wear resistance is a near constant relationship between load and the coefficient of friction. A sharp increase in the coefficient of friction would strongly indicate that destructive wear is occurring.

The plot of the static coefficient of friction versus load for the unlubricated steel specimens (Fig. 1) reveals a tendency for the coefficient to rise with increasing load. At lower loads this increase in the coefficient appears to be caused by some slight destructive wear at the surfaces. This wear was probably caused by light scuffing or minor welding between the steel specimens. At a higher load the wear was much more severe as definite galling occurred and there was a sharp increase in the coefficient of friction.

The dry, chromium-plated specimens exhibited much better wear resistance than steel. The plot of the static coefficient of friction versus load (Fig. 2) showed that there was an approximately constant relationship. At the conclusion of the static test, the chromium-plated specimens showed no visual damage as the galling tendency of chromium was much less than that of steel.

The static friction tests for dry, hard-anodic coatings and dry phosphat coatings revealed that little or no destructive wear occurred. The coefficients of friction were higher than for either the steel or chromium-plated specimens, but the coefficients remained reasonably constant with an increase in load (Figs. 3 and 4).

2. Appendix B - Bibliography, Listing No. 2

3. Appendix B - Bibliography, Listing No. 3

3. RESULTS AND DISCUSSION - Continued

Two significant points are noticeable from the results of the wear tests involving combinations of two different materials. The results of tests of dry steel in contact with either chromium plate or hard-anodized aluminum show that some destructive wear occurs at the steel surface. In Figures 5 and 6, the static coefficient of friction increased gradually as the load was increased. In Figure 7, however, when a dry, phosphate-coated specimen is in contact with a steel specimen, the static coefficient of friction remained constant with increase in load. Phosphate coatings, when in contact with a smooth steel surface, appear to reduce significantly the possibilities of galling.

The results for the endurance tests on the various surfaces can be seen in Figure 11. The endurance tests consisted of a dynamic test at 600 rpm and a relatively high load (307.1 pounds). The poor wear resistance of steel is substantiated by the fact that the specimens were severely galled after approximately 2-1/2 minutes or 1500 cycles. The chromium-plated samples underwent severe wear after approximately six minutes. The specimens were well-lubricated prior to testing. During the dynamic test, sufficient lubricant was retained on the surface of the movable block, but the amount of lubricant on the upper surface gradually diminished as the test progressed. The failure attributed to galling usually occurred at the upper surface because of this lack of lubrication.

The endurance test for phosphate coatings and hard-anodized coatings (Fig. 11) reveals that the wear resistance of both coatings is better than that of chromium. The primary factor influencing this result is believed to be the surface roughness of the individual coatings. The hard-anodized coating and the phosphate coating are porous and have the ability to absorb and retain lubricants, while the chromium-plated specimens had been polished and had the ability to retain oil.

It is also interesting to note from Figure 11 that the failure of steel and chromium blocks was very abrupt. It appeared that the lack of lubrication in areas led to rapid overheating and, consequently, galling occurred instantaneously. The coefficient of friction versus the number of cycles for the hard anodic and phosphate coatings shows, in time, a gradual increase in the coefficient caused by the simultaneous loss of lubricant and wearing away of the coating. The sharp increase in the coefficient for hard-anodized aluminum after approximately 11,000 cycles represents the point at which the hard-anodized coating was completely removed and bare aluminum was exposed. It appears that inorganic finishes, such as hard anodic and phosphate coatings, have better galling characteristics, in general, as compared to metallic surfaces.

b. Coefficient of Friction

Hardness is considered to be a significant factor influencing the resistance of a material. This is because surfaces undergo compressive stress while wearing conditions are present, and since hardness tests are usually performed under compressive conditions, hardness can be employed as a significant index of merit.⁴

3. RESULTS AND DISCUSSION - Continued

Hardness also might be expected to have some influence on the coefficient of friction because of its close association with wear resistance. The hardness values for chromium plate and hard anodic coatings are generally considered to be relatively high, although the values vary considerably and are sometimes difficult to obtain. The hardness of bright chromium plate is equivalent to 950 to 1050 Vickers. Microhardness tests on hard-anodized surfaces have shown hardness values of 530 VPN for a coating produced by the Martin hardcoat process on 6061-T6 alloy.

A comparison of the static coefficients of friction between the dry chromium plate and hard-anodized surfaces showed that the chromium on chromium plate had a much lower coefficient of friction. The static coefficient for chromium plate averaged .16 while the static coefficient for hard-anodized aluminum on hard anodized aluminum averaged .55 (Figures 2 and 3). The difference in the coefficients appears to be a function of the surface roughness rather than the hardness of the respective samples. The surface roughness of the chromium plate was three to four microinches while the hard anodic coatings were 45 to 55 microinches (rms). The coefficients of friction for hard anodic coatings have been quoted to be below .15, but these values are for hard anodic surfaces which have been lapped or honed after anodizing to improve the surface finish.

The chromium-plated and steel specimens had approximately the same surface finish. The static coefficient of friction for steel was always higher than that for chromium, even at the lightest loads where no galling occurred for the steel. The minimum coefficient for steel was .20 at a load of 32.1 pounds.

Very high static coefficients of friction were obtained when phosphate-coated blocks were in contact with each other. The high coefficient was primarily caused by the rough nature of the grit blast pretreatment. The dry phosphate coating might retard galling tendencies; however, it did not improve the lubricity between the rough surfaces.

The dry phosphate coatings in contact with smooth surfaces, such as the chromium plate and bare steel samples, had a much lower coefficient. The static coefficient of friction was less than .2 (Figs. 7 and 8). The phosphate coating in contact with the smooth surface during the break-in period prevented metal-to-metal contact and appeared to have some beneficial lubricating qualities. The dry phosphate coating in contact with the rough hard-anodized surface did not improve the static coefficient of friction (Fig. 10).

c. Lubrication

The lubricant used throughout this investigation was MIL-L-644 oil. This general purpose preservative and lubricating oil is suitable for use in lubrication and corrosion protection of small caliber weapons.

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3. RESULTS AND DISCUSSION - Continued

The coefficients of friction of the various surfaces, when lubricated, did not vary to any extent from coating to coating. The only exception to occurrence was in the case of the steel-on-steel specimens, when the static coefficient reached values as high as .18. The static coefficient for all other coatings was usually in the range of from .13 to .15, while the dynamic coefficient usually was in the range of from .12 to .15.

The results indicated that during the simulated static test, the slight excess of oil present produced hydrodynamic lubrication in which no metal-to-metal contact was present. In the case of steel on steel, hydrodynamic lubrication was probably not completely present since the smooth surfaces had no cavities to retain oil. The lubricated chromium specimens, although they were equally as smooth, did not have a higher coefficient of friction.

During the dynamic testing, the load was increased approximately every 30 seconds. Hydrodynamic lubrication was not present when the higher loads were applied. This was evident because the samples were polished and scratched to some extent. The dynamic coefficient of friction, however, did appear to be significantly affected by the change in type of lubrication. The coefficient in some cases was slightly higher at the higher loads. This increase in the coefficient occurred in random fashion and could not be associated with any particular coating or coatings. It is believed to be primarily caused by vibrational effects at some loads in which the weights on the lever arm were not held stable.

The static and dynamic coefficients of friction for well-lubricated surfaces strongly indicate that the coefficients of friction are primarily dependent upon the nature of the lubricant, while the coating has little or no influence upon the coefficient. The minimum coefficient of friction provided by MIL-L-644 oil appears to be approximately .12. Although no systematic study involving another lubricant was made, friction tests of a dry film lubricant on hard anodized aluminum showed that the static coefficient was reduced to approximately .09.

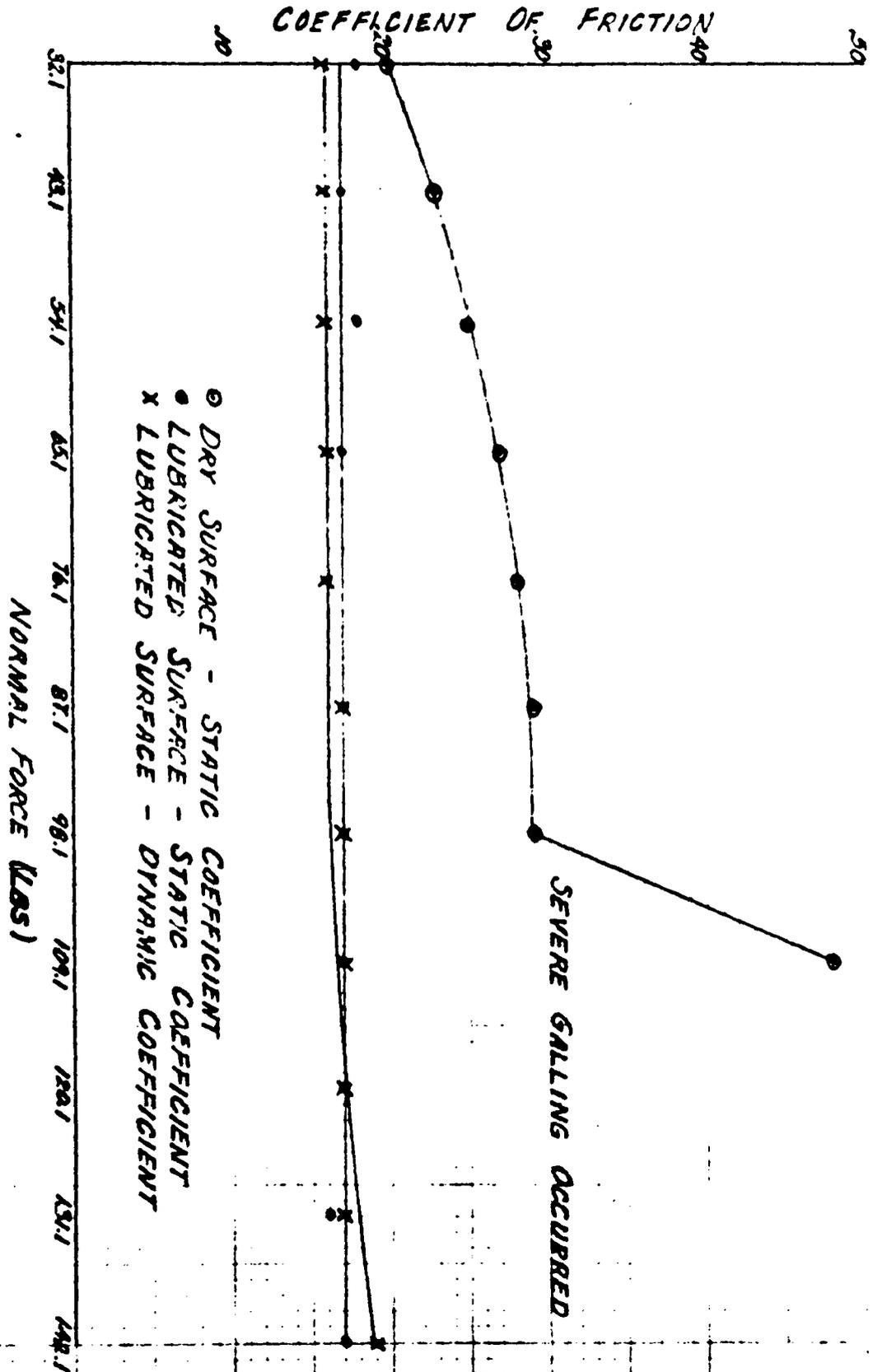
APPENDICES

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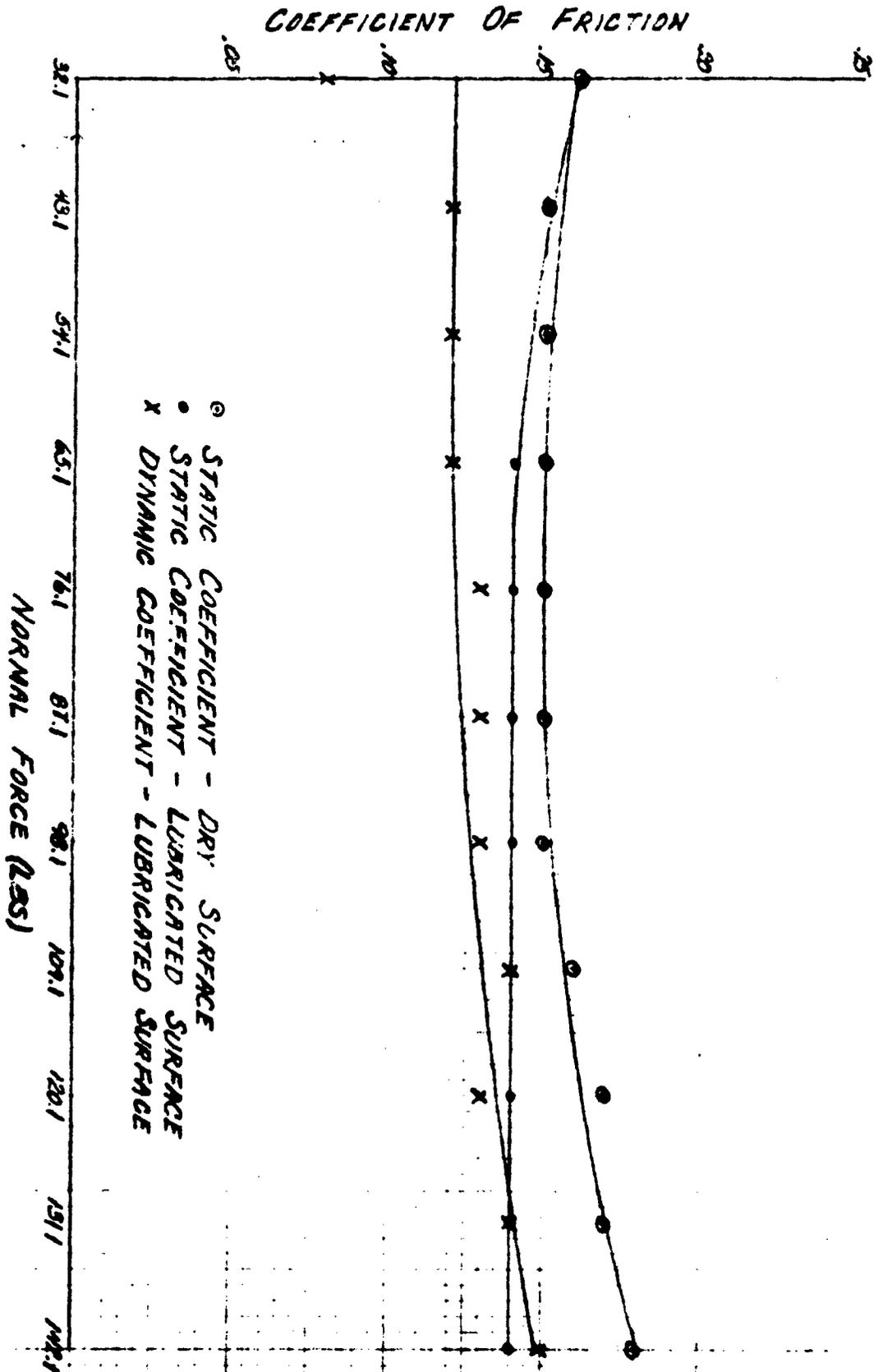
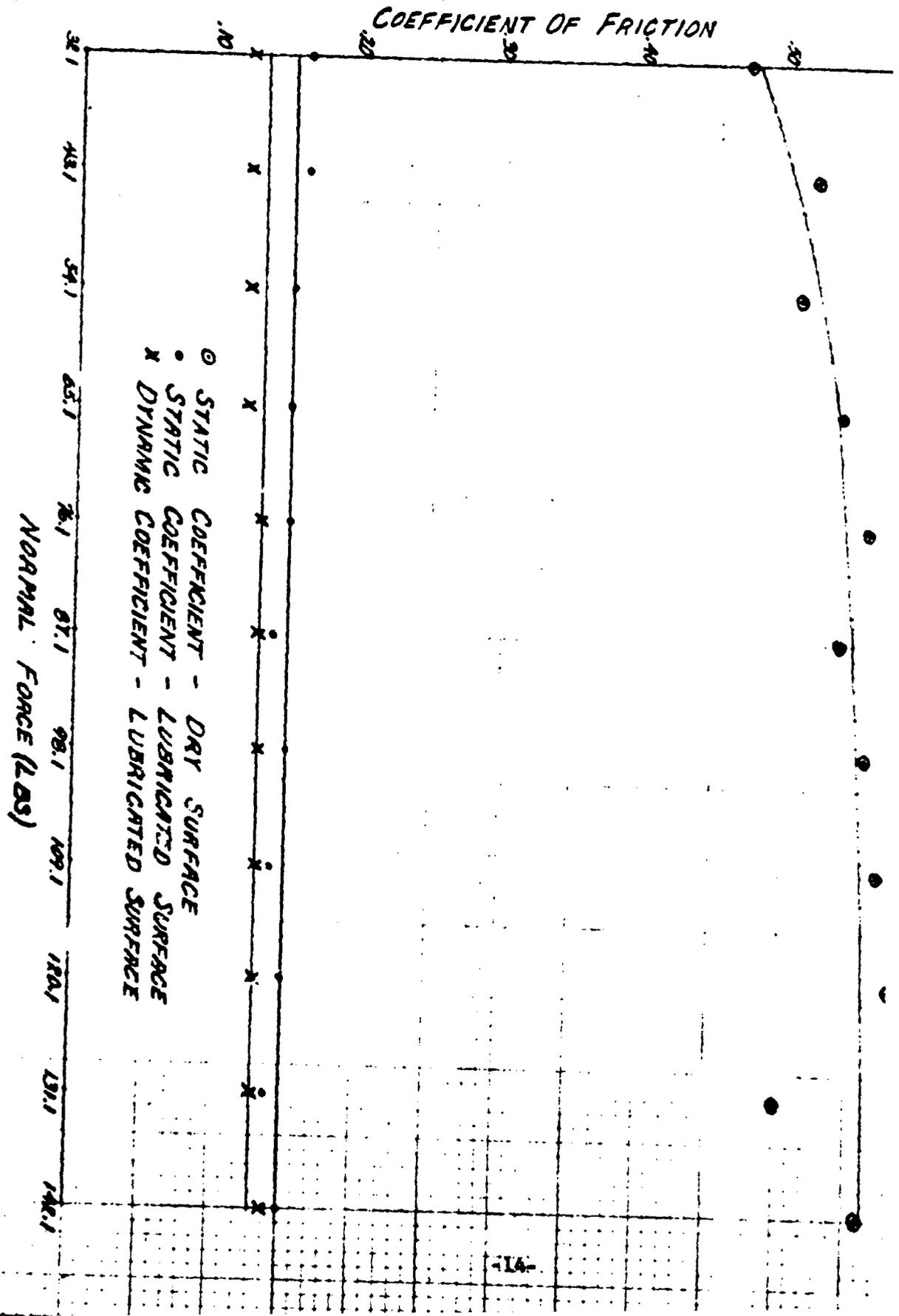


FIGURE 2
CHROMIUM ON CHROMIUM



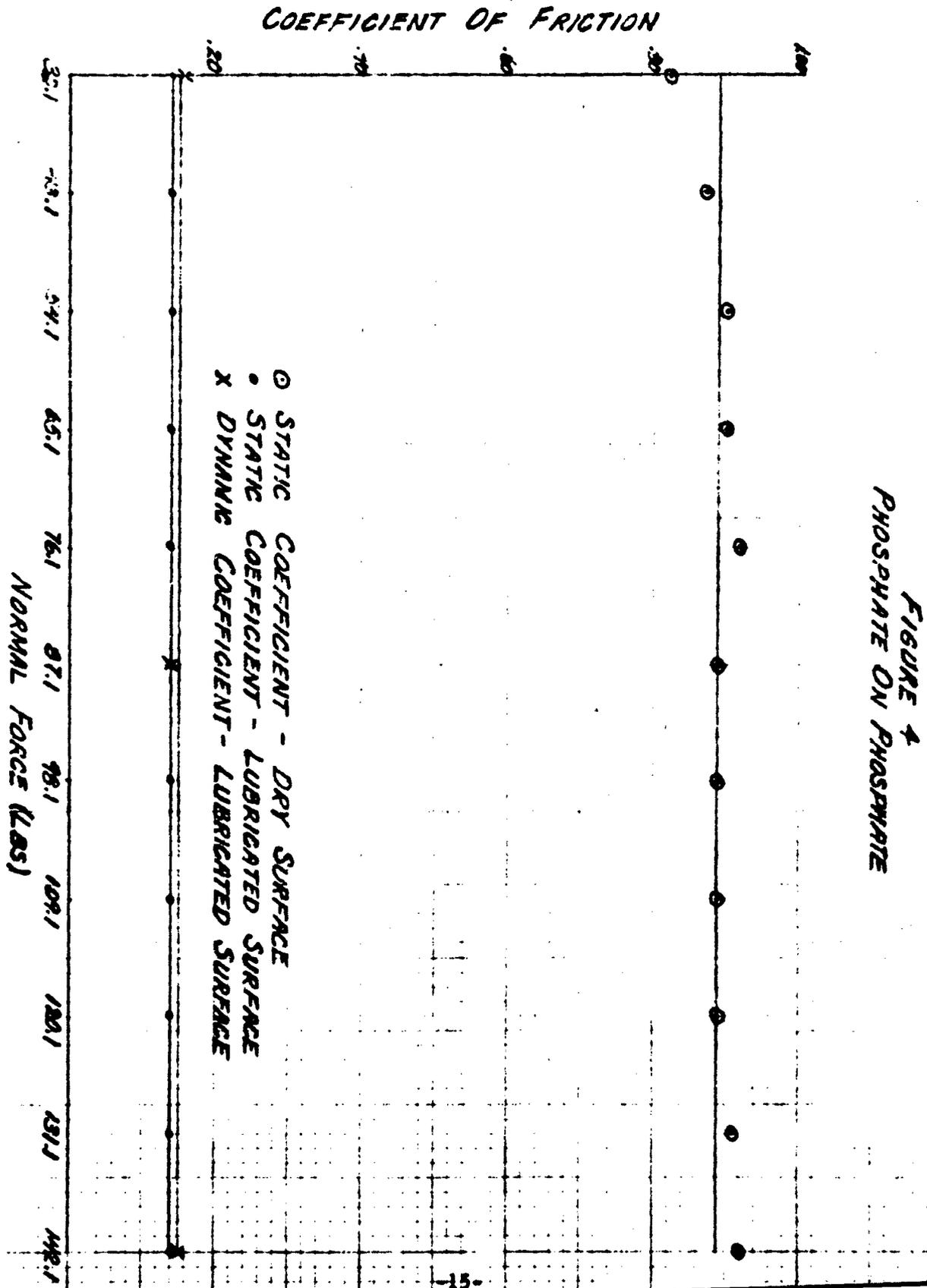
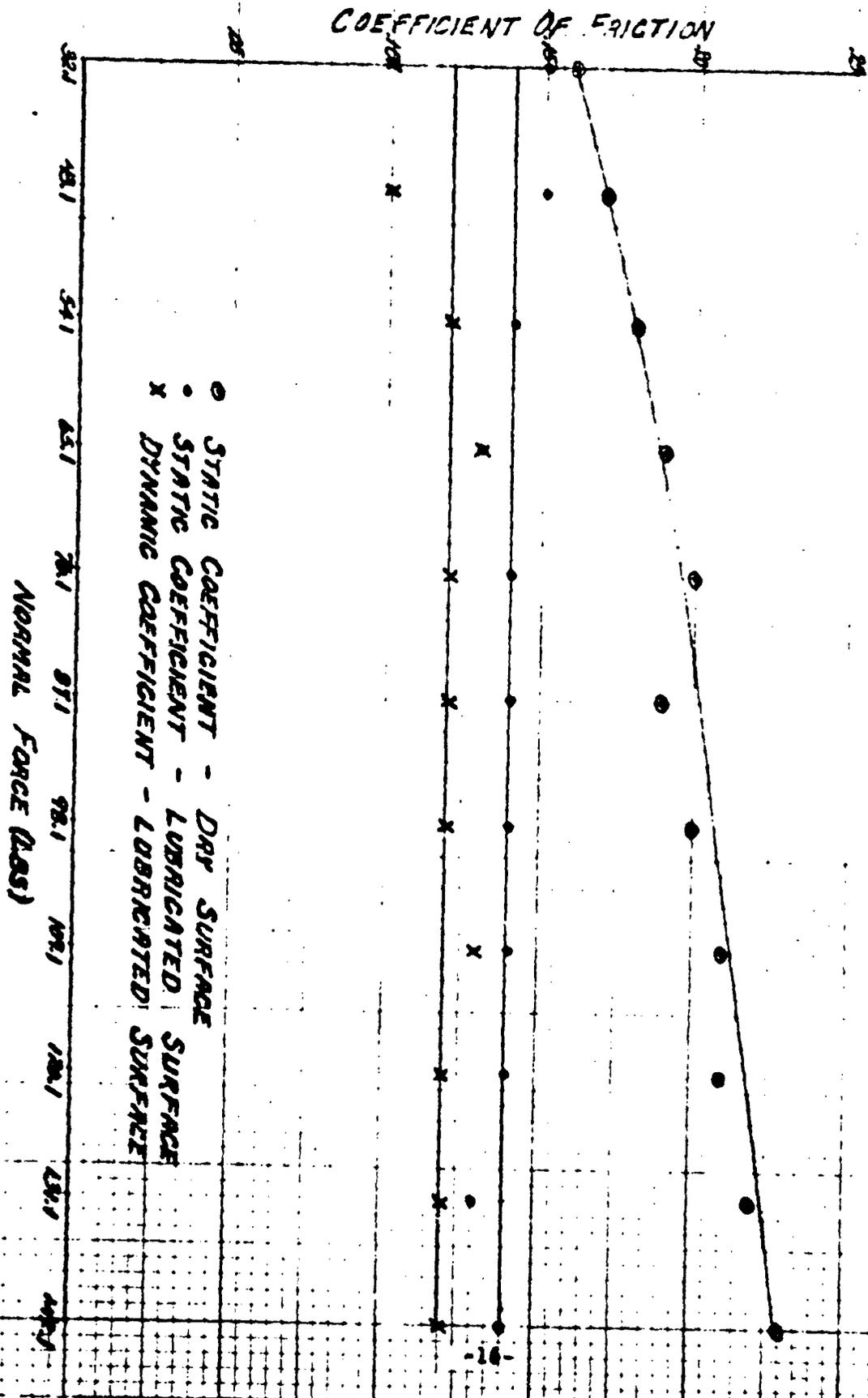


FIGURE 4
PHOSPHATE ON PHOSPHATE



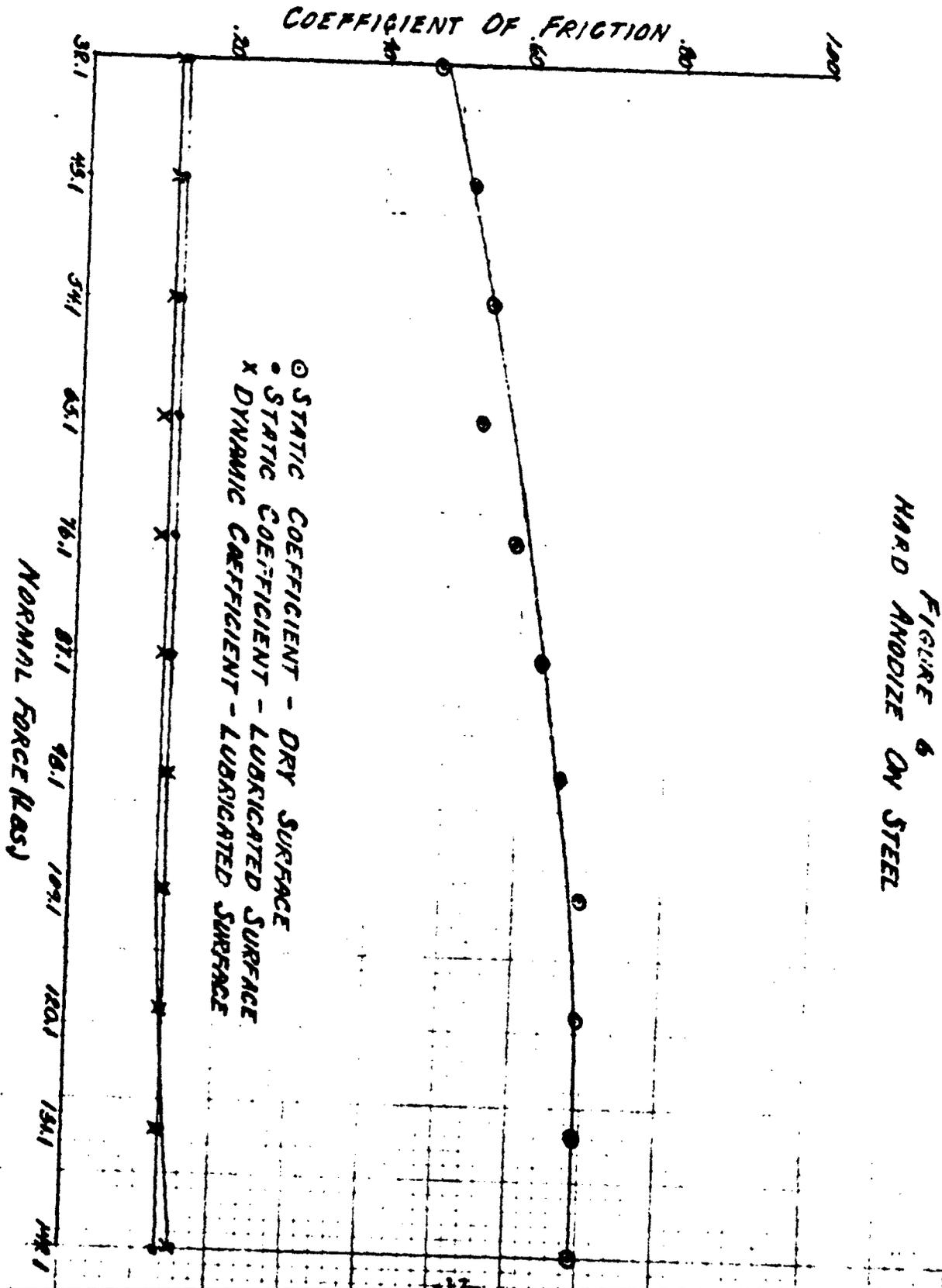
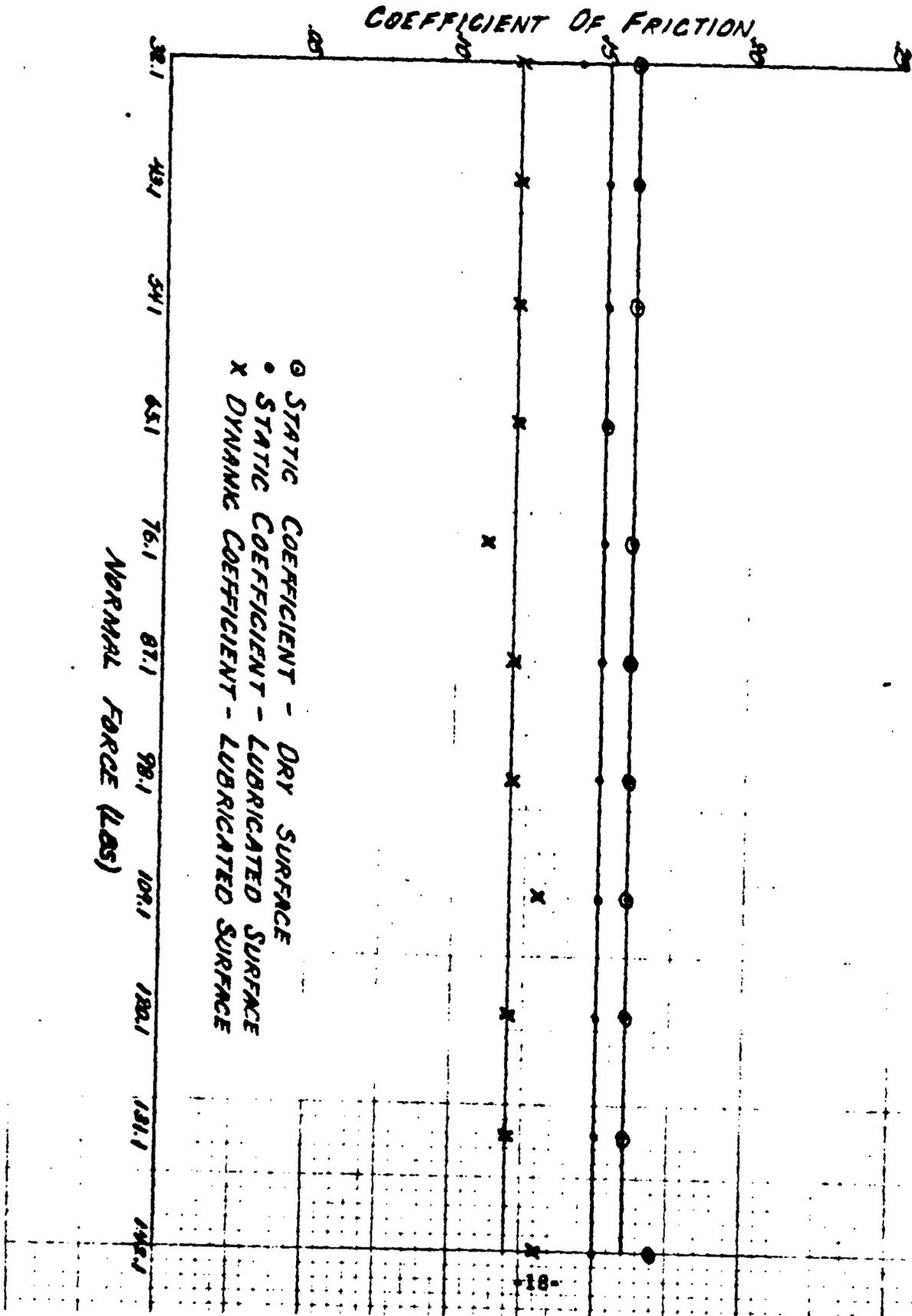


FIGURE 6
HARD ANODIZE ON STEEL



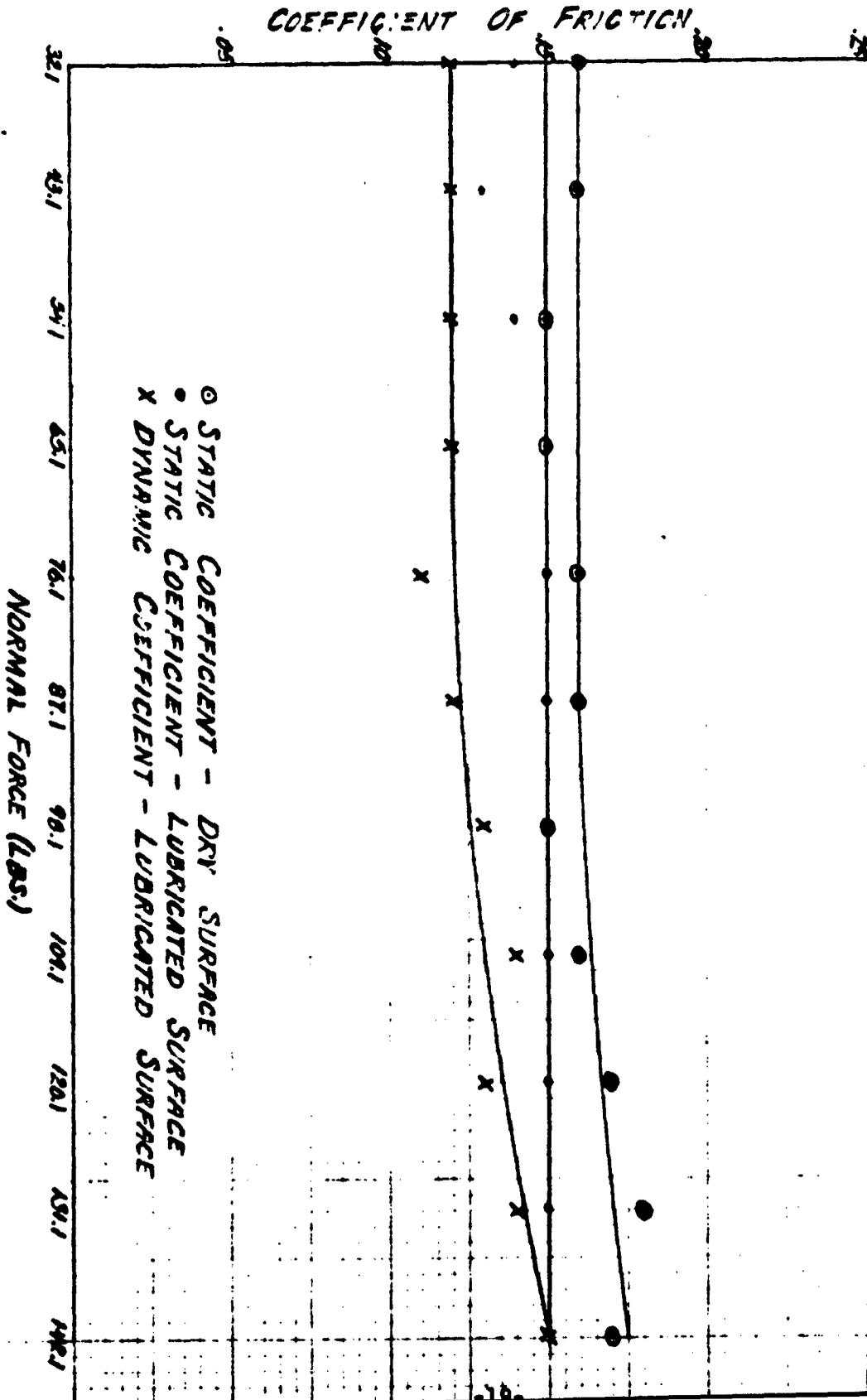
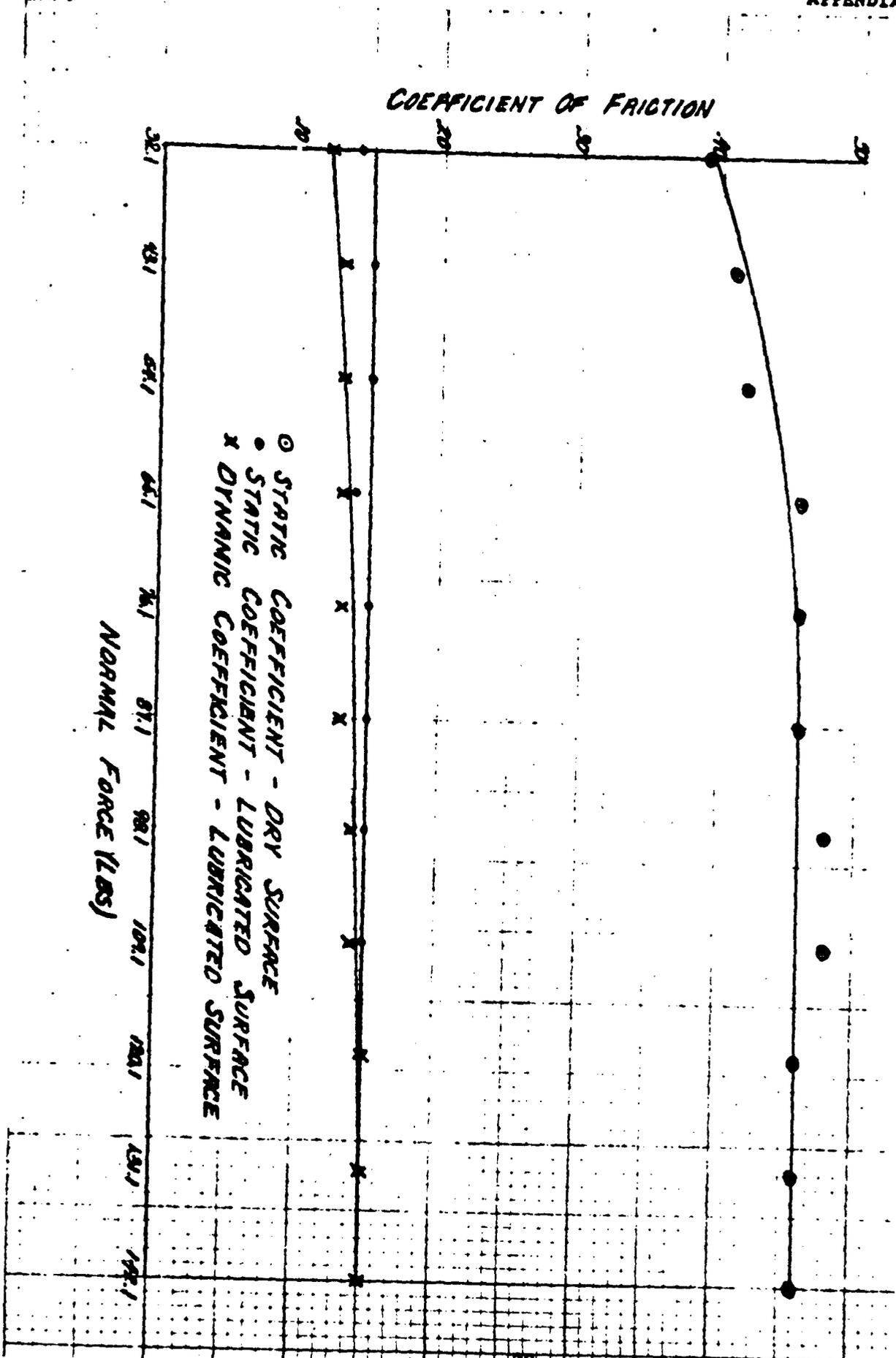


FIGURE 8
PHOSPHATE ON CHROMIUM



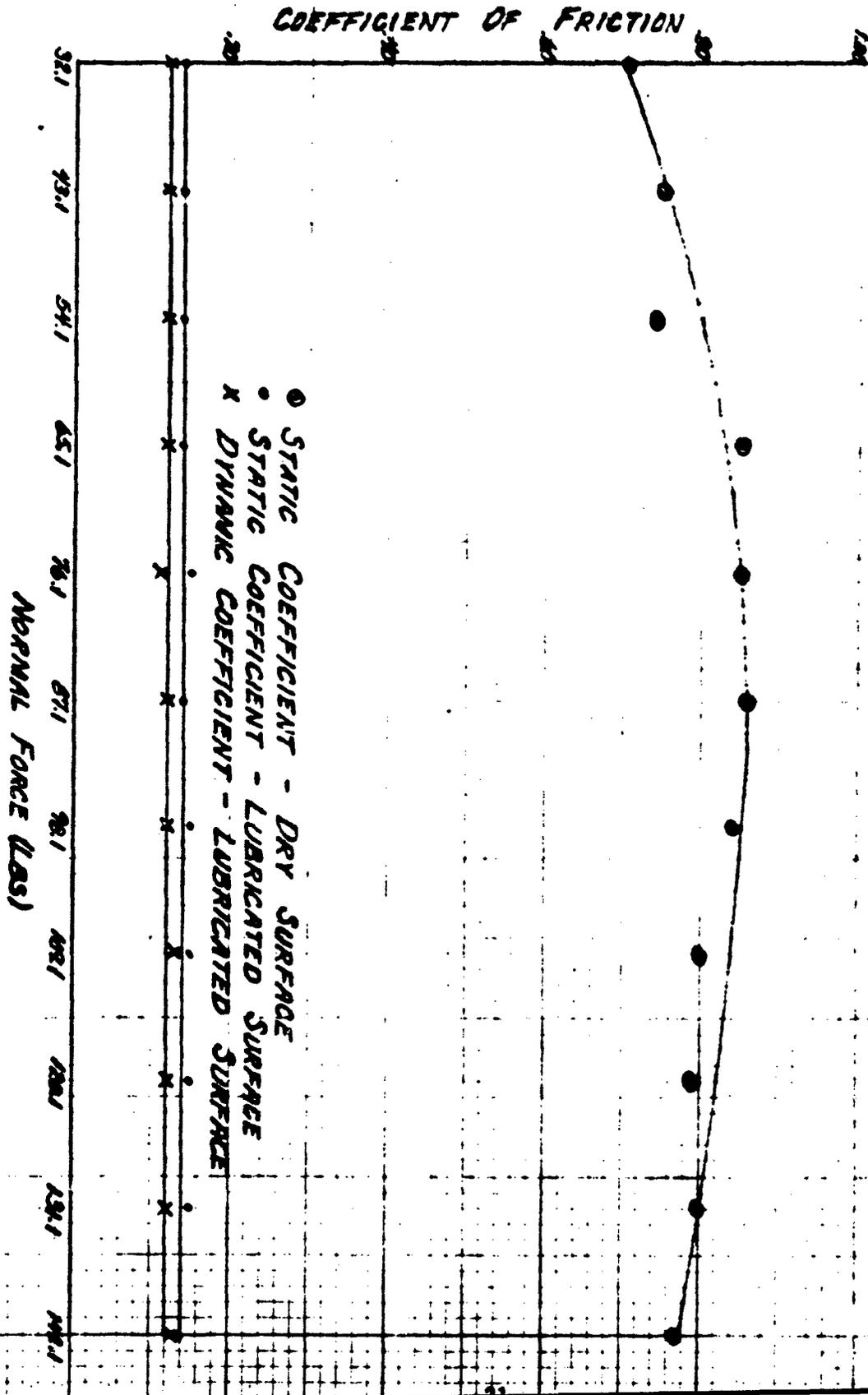
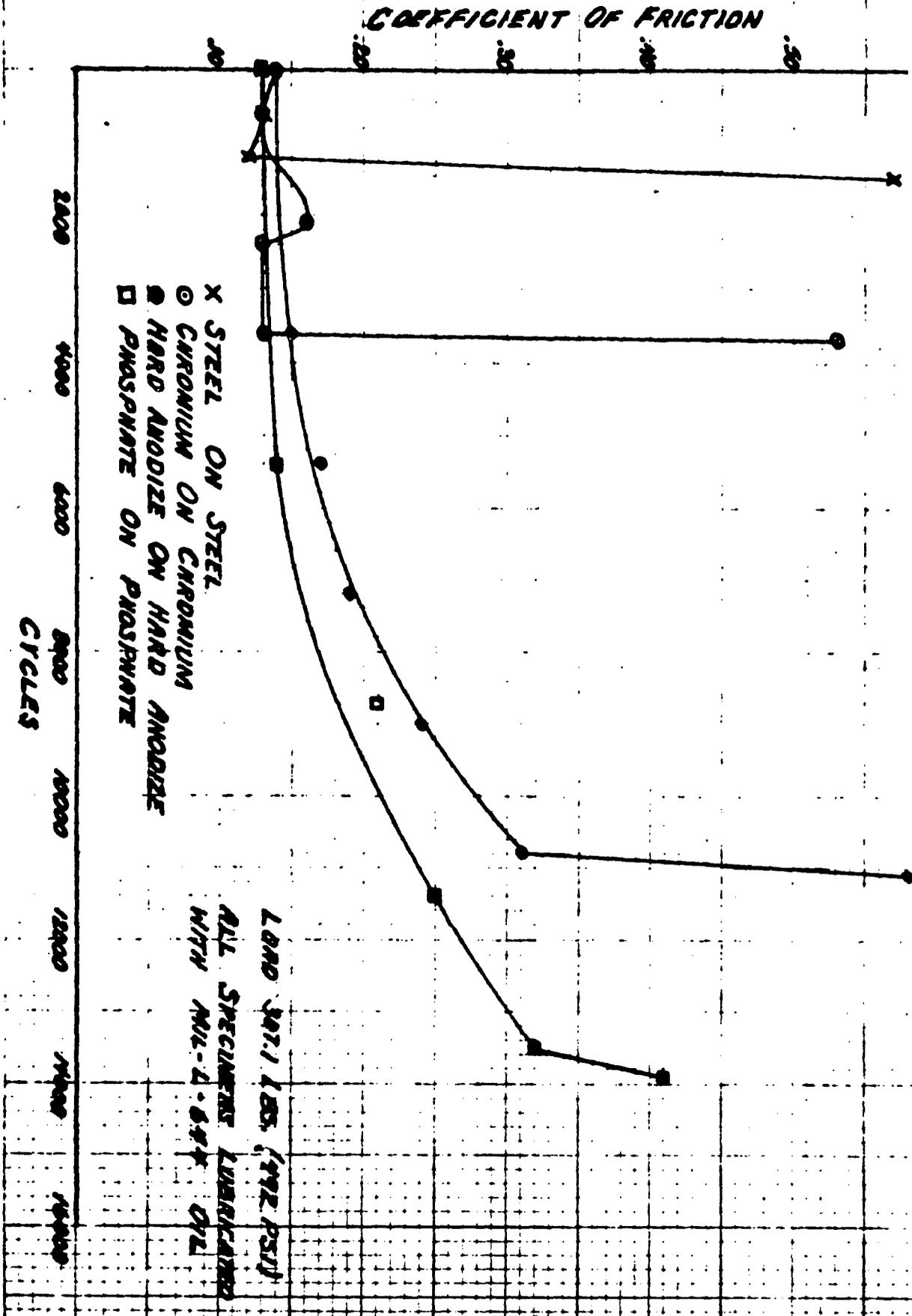


FIGURE 10
PHOSPHATE ON HARD ANODIZE



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UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)		2a. REPORT SECURITY CLASSIFICATION	
Springfield Armory, Springfield, Massachusetts		UNCLASSIFIED	
		2b. GROUP	
		N/A	
3. REPORT TITLE			
FRICTIONAL AND WEAR CHARACTERISTICS OF VARIOUS COATINGS USED ON SMALL CALIBER WEAPON COMPONENTS			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)			
Technical Report			
5. AUTHOR(S) (Last name, first name, initial)			
George, M. A.			
6. REPORT DATE		7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
17 September 1965		28	5
8a. CONTRACT OR GRANT NO. N/A		9a. ORIGINATOR'S REPORT NUMBER(S)	
b. PROJECT NO. M1-4-50020-01-M1-M6		SA-TR18-1089	
c. AMCMS CODE 5016.11.84400.02		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
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11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY	
None		U. S. Army Materiel Command	

13. ABSTRACT

Friction and wear studies, in which Springfield Armory friction and wear machine was used, were continued. Information relating to the frictional and wear properties of coatings was obtained under simulated weapon conditions. Various coatings such as phosphate, chromium plate, and hard-anodized aluminum were evaluated. The rough porous coatings such as phosphated steel and hard-anodized aluminum generally had high coefficients of friction when unlubricated, but exhibited good wear resistance when lubricated. Chromium plate, when unlubricated, had a lower coefficient of friction than steel of equal surface roughness. Metallic surfaces such as chromium plate and hardened steel had limited antigalling properties. Procedure is given, and results are discussed.

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14. KEY WORDS	LINK A		LINK B		ROL
	ROLE	WT	ROLE	WT	
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2. Protective treatments					
3. Metal finishing					
4. Lubrication					
5. Small caliber weapons					

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It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract end with an indication of the military security classification of the information in the paragraph, represented as (TS (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful or short phrases that characterize a report and may be index entries for cataloging the report. Key words must be selected so that no security classification is required. Suffixes, such as equipment model designation, trade name, project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

