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FRICTION AND WEAR OF COBALT-MOLYBDENUM AND COBALT-MOLYBDENUM-CHROMIUM ALLOYS FOR PROSTHETICS

by Robert L. Johnson and Max A. Swikert

Lewis Research Center
Cleveland, Ohio 44135

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16. Abstract

Studies were conducted in heptane with cobalt alloys on a disk-and-conforming-shoe apparatus simulating the single motion of a human hip joint. The results showed that cobalt-molybdenum-chromium alloys were brittle; that the surface finished by grinding fragmented locally; and that, subsequently, abrasion of sliding surfaces occurred. When the ground surfaces were altered by glass-bead blasting, fragmentation during the wear process was minimized. Particles loosened by the grinding process were removed, and the bead-blasted surface provided pockets to entrap debris. Friction and wear for the bead-blasted cobalt-molybdenum-chromium alloy were significantly lower than for vitallium.

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SUMMARY

Friction and wear studies were conducted, in heptane with an argon atmosphere, with cobalt-molybdenum and cobalt-molybdenum-chromium alloys. Experiments were conducted with an oscillating-disk-and-conforming-shoe apparatus simulating simple conditions in a human hip joint.

Various surface textures and passivation by preoxidation were studied. The results of the investigation indicate that glass-bead blasting of cobalt-molybdenum-chromium alloy surfaces removed fragmented particles loosened by the grinding process and provided pockets to entrap debris. Wear and friction were reduced, and friction values were stable. Improved friction and wear were obtained with passivation by preoxidation. Friction and wear for the bead-blasted cobalt-molybdenum-chromium alloy were significantly less than for vitallium.

INTRODUCTION

For several years, the NASA Lewis Research Center has been conducting basic materials research on metals and alloys for bearing surfaces to be used in the vacuum of outer space. The alloys had to be capable of sliding together under load in vacuum without surface failure and with relatively low wear. These studies indicated that cobalt alloys with hexagonal structure have lower friction and wear than cobalt alloys with cubic structure. One of those alloys chemically resembles vitallium, a cobalt-chromium alloy used most commonly for hip replacements. The properties of vitallium have been studied by many scientists and are reported in references 1 and 2. The friction and wear properties of the materials, cobalt-molybdenum and cobalt-molybdenum-chromium alloys with hexagonal crystal structure, are reported in reference 3.

Materials used for body implant prosthetics require careful study of both the chemical compatibility and physical properties. The tissue compatibility for cobalt-molybdenum hexagonal alloys is reported in reference 4. The addition of chromium to the cobalt-molybdenum alloy was necessary to achieve compatibility. The Cornell Medical Center has cooperated with NASA in obtaining tissue compatibility data.

The physical properties of alloys are changed by heat treatment and by the addition of alloying elements (i. e., the addition of chrome to the cobalt-molybdenum alloy increases both hardness and brittleness). This is important to materials that are to be used in sliding contact as in a full hip joint prosthesis.

The object of these studies is to determine the friction and wear properties of a cobalt-molybdenum alloy and a cobalt-molybdenum-chromium alloy with varied surface finishing. These studies were made on an apparatus simulating simple motion conditions in a human hip joint.

APPARATUS

The apparatus used in this investigation is shown in figure 1. The disk specimen was 44. 4 millimeters (1. 75 in.) in diameter by 12. 7 millimeters (0. 5 in.) thick. The shoe specimen was a 120° segment of a circle and was 12. 7 millimeters (0. 5 in.) thick. It had a conforming fit with the outside diameter of the disk. The disk specimen simulated the cross section of a femoral head and the shoe specimen simulated the acetabular cup.

The disk specimen was mounted on a shaft and oscillated by a reciprocating drive at 0. 97 hertz (58 cpm) through a 40° arc. The shoe specimen was mounted inside a housing that was restrained by a strain gage dynamometer through a forked-shaped fixture with cables. The load was applied to the shoe through the housing with a pneumatic cylinder, flexure pivot, and cables. The 47. 2-kilogram (104-lbm) load on the specimen produced a projected unit load equivalent to the stress on a ball and socket of a human hip joint.

Heptane was used as a fluid and supplied to the specimen with a tubing pump driven by a variable-speed, direct-current motor. A rotameter was used to monitor the flow of heptane at 0. 6 milliliter per minute. The fluid was supplied at the sliding interfaces through a tube in the housing and a hole in the top of the shoe specimen. A gravity drain was provided in the bottom of the housing. The fluid was not recirculated.

The housing was continually purged with dry argon during the experiments to assure controlled conditions. All experiments were run at room temperature.

PROCEDURE

Specimen Preparation

Grinding and metallographic polishing and cleaning techniques were used to prepare the specimens as follows: Both specimens were first ground to a 0.102- to 0.203-micrometer (4- to 8-μ in.) root-mean-square surface finish and matched in pairs (one disk and one shoe) to a conforming fit. Visual examination was used to determine conformity. The surfaces were then polished with moist levigated alumina and a clean white flannel cloth until the cloth no longer discolored from the polishing process. Distilled water and another clean cloth were used to remove levigated alumina. The specimen surfaces were rinsed with 100-percent ethyl alcohol. The specimens were then placed in a vacuum oven and heated to 93° C (200° F) at 0.133 N/m^2(1 torr) for 24 hours to remove all final traces of alcohol and water. The specimens that were passivated with preoxidation by heating in air at 800° C (1472° F) for 24 hours were also given a crystal structure stabilization heat treatment at 371° C (698° F) for 48 hours.

Test Procedure

Each specimen was removed from the vacuum oven and weighed with a microbalance just prior to mounting on the apparatus. An initial run-in procedure was used in all experiments. The load and time are shown in table I. The experiments at test conditions were run for 66 hours (equivalent to walking 160.9 km (100 miles)) at 0.97 hertz (58 cpm) and a load of 47.2 kilograms (104 lbm) (equivalent stress to that of a 81.8-kg (180-lb) person). Friction force measurements were made with the strain gage dynamometer running for 5 minutes out of every hour and recorded on magnetic tape. A

TABLE I. - RUN-IN CONDITIONS

Time, min	Load, kg	Time, min	Load, kg
2	6.35	10	29.1
3	12.7	↓	32.2
5	15.9		35.4
10	19.2		38.6
10	22.7		44.5
10	25.9		

time code signal was also recorded on the tape at the same time. The tape could then be played and examined on an oscilloscope or recorded on a strip chart at various tape or chart speeds.

At the completion of each experiment the test specimens were removed from the apparatus and very lightly cleaned with levigated alumina (just enough to remove contaminants). The rinse in water and in alcohol and the oven drying were the same as before the experiment. The specimens were again weighed after each experiment to determine weight loss. These values were used as a measure of wear. Weight loss measurements of the order of 0.1 milligram were not considered significant; wear was considered low and not measurable.

RESULTS AND DISCUSSION

Results of previous NASA studies (ref. 3) indicated that cobalt alloys with hexagonal structure in sliding contact in vacuum have lower friction and wear than cobalt alloys with cubic structure.

Examination of full vitallium hip joint prosthetics that were removed from human patients after periods of about 1 year showed some galling and metal transfer at the surface (ref. 5). This was not surprising because vitallium is a cobalt-chromium alloy with a predominantly cubic structure. The alloys used in these experiments are listed in table II along with physical and chemical properties important to this investigation.

TABLE II. - PROPERTIES OF TEST ALLOYS

Alloy	Chemical composition, percent	Hardness, R_C	Surface finish			Crystal structure
			Method	rms		
				μm	μ in.	
Vitallium	29 Cr 5 Mo 2 Ni 64 Co	27	Grinding	0.336	13	Cubic (predominantly)
Co-Mo	25 Mo 75 Co	47	Grinding	0.152	6	Hexagonal
Co-Mo-Cr	25 Mo 10 to 15 Cr 60 to 65 Co	50	Grinding Grit blasting Al_2O_3-powder-and-water-vapor blasting Glass-bead blasting	0.152 1.19 .661 .838	6 47 26 33	Hexagonal

Vitallium, a predominantly cubic crystal structure alloy used in present day prosthetics, was used as a control material for comparison purposes in those experiments. Heptane was used as a fluid because its lubricating qualities resulted in wear processes that duplicated those found to have developed in used protheses removed from human patients. Many human joint problems are accompanied by diseased synovial fluid. Changes in the synovial fluid (e.g., hyaluronic acid component) are considered to adversely influence lubricating ability. The synovial fluid becomes an inadequate lubricant under these conditions, and the human joint fails. The sliding surfaces of a prosthesis must function under poorly lubricated conditions.

Initial experiments were run with vitallium and a cobalt alloy of 25-percent molybdenum with a hexagonal crystal structure lubricated with heptane. The friction and wear results are shown in figure 2. The friction coefficient for vitallium with a ground surface was 0.25; and for the cobalt-molybdenum alloy with a ground and glass-bead-blasted surface, it was 0.15. This is a significant decrease in friction coefficient and could be very important to the recipient of a prosthetic device. The wear for the vitallium was over 1000 times that of the cobalt-molybdenum alloy. The wear weight-loss measurements for the cobalt-molybdenum alloy could not be measured with accuracy because of the degree of difficulty required to control conditions with the very low wear. Photomicrographs in figure 3(a) show adhesion and metal transfer with the vitallium. Figure 3(b) shows no visible metal transfer with the cobalt-molybdenum alloy. Photomicrographs and surface profile traces of these two alloys are shown in figure 4.

Tissue compatibility studies of the cobalt-molybdenum alloy, reported in reference 4, showed slight corrosion with implants in rabbits. To improve corrosion resistance, the cobalt-molybdenum alloy was modified by the addition of 10- to 15-percent chromium without change in hexagonal crystal structure. The hardness and brittleness of the cobalt-molybdenum alloy increased with the chromium addition. Microscopic examination and surface profile showed no visible changes in the surface. The initial friction and wear experiments with the cobalt-molybdenum-chromium alloys in the as-ground condition showed abnormalities that resulted from surface fragmentation. The coefficient of friction was 0.38, which is somewhat higher than that of the control alloy vitallium. The wear was similar to that with the vitallium. The friction and wear data are presented in figure 2. Figure 5 is a comparison of friction traces for the cobalt-molybdenum and cobalt-molybdenum-chromium alloys with ground surface finishes. The scatter in the friction data for the cobalt-molybdenum-chromium alloy is quite apparent. Microscopic examination of the surface of the cobalt-molybdenum-chromium alloy after operation showed brittle fracture. Typical photomicrographs of fractured and fragmented surfaces are shown in figures 6(a) and (b). It appeared that local fragmentation was initiated during finish grinding.

Surface Treatment

The problem of fragmentation is important where fragments are trapped and serve as abrading particles, as in the conforming-shoe friction apparatus and in a ball-and-socket prosthesis. Procedures were selected to remove fragment particles loosened by the grinding process and to provide pockets to entrap debris; also, local lubricant reservoirs would be formed. The techniques examined were grit blasting, aluminum-oxide-water-vapor blasting, and glass-bead blasting. Figures 7(a) to (d) are typical photomicrographs and surface profile traces of each of the surfaces studied. Figure 7(a) is the ground surface used with all specimens. Other treatments were subsequent to grinding. The photomicrograph of figure 7(b) shows fragmentation of the grit-blasted surface. A rough irregular surface is visible from both the photomicrograph and the profile trace. The roughness finish was 1.19 micrometers (47 μ in.) root mean square.

Both the friction and wear for the grit-blasted finish were slightly higher than those for the ground surface (fig. 8). Surface damage due to fragmentation and subsequent abrasion was similarly severe for both surfaces. It is likely that the sharp grit and impaction of the blasting process increased brittle fracture at the surface.

The friction coefficient for the Al_2O_3-powder-and-water-vapor-blasted surface was 0.33, and the wear was slightly higher than that for the ground surface. The surface shown in the photomicrograph of figure 7(c) had a matted nondirectional surface. The surface profile trace in figure 7(c) shows that the surface did not have sharp peaks as did the grit-blasted surface of figure 7(b). Although there was some fragmentation of the surface after the experiment, the degree was much less than with the ground or grit-blasted surfaces after the experiment.

The best results were obtained with the glass-bead-blasted surface. A photomicrograph and surface profile trace of this surface are shown in figure 7(d). This process removed brittle fragments and produced a typical grain-boundary dentritic structure. Experience showed that a reduced air pressure was necessary in the glass-bead blasting gun to prevent further fracturing the surface and leaving voids. Such voids typically may be 0.013 millimeter (0.005 in.) deep. Both the friction and wear were comparable with those of the cobalt-molybdenum alloy with a ground surface finish (fig. 8 compared with fig. 2).

The cobalt-molybdenum alloy material was also examined with the glass-bead-blasted surface to determine if further improvement could be made in this alloy. The friction and wear results were the same as for the ground surface alloy (fig. 9). The variation in individual friction data points was less for the glass-bead blasted surface, however.

Vitallium, the cobalt-chromium alloy, was run with the glass-bead-blasted surface. This material had a hardness of 27 Rockwell C as compared to 50 Rockwell C for the cobalt-molybdenum-chromium alloy and did not have the brittleness property that accompanies high hardnesses. The friction coefficient was 0.38 and was accompanied by adhesive wear. The wear weight loss for vitallium was slightly higher for the glass-bead-blasted surface than for the ground surface.

It is reported in reference 6 that oxides of cobalt and molybdenum form protective oxides on surfaces in sliding contact. With this background, passive oxide layers were preformed on the contact surfaces to determine possible gains in reduced friction and wear. Passive oxide layers were formed on both the ground and glass-bead-blasted cobalt-molybdenum-chromium alloy. The coefficient of friction was 0.21 for both specimens. The wear was also the same for both surfaces (fig. 10). Passivation decreased wear and friction of ground surfaces but increased wear and friction of the glass-bead-blasted surface.

The cobalt-molybdenum-chromium alloy with the glass-bead-blasted surface showed reduced friction and wear over the vitallium with the ground surface. The friction coefficient was reduced from 0.25 for the vitallium to 0.17 for the cobalt-molybdenum-chromium alloy, and the wear weight loss was reduced from 0.108 gram for the vitallium to a value so small it was not measurable for the cobalt-molybdenum-chromium alloy.

SUMMARY OF RESULTS

The investigation of friction and wear of cobalt-molybdenum and cobalt-molybdenum-chromium alloys with varied surface treatments was conducted in an apparatus simulating simple conditions in an artificial human hip joint. Slight corrosion found with cobalt-molybdenum specimens in rabbit tissue tests indicate inadequate compatibility for prosthetics; there was no apparent compatibility problem with the cobalt-molybdenum-chromium alloy. The following results were obtained:

1. Friction and wear of the cobalt-molybdenum-chromium alloy with the glass-bead-blasted finish were significantly lower than for vitallium with ground surfaces; of the treatments used, these were the best finishing methods for the respective alloys.

2. Glass-bead blasting of ground surfaces reduced friction and wear of the cobalt-molybdenum-chromium alloy by removing fragments and particles and providing pockets for entrapping debris. Glass-bead blasting of the ground cobalt-molybdenum alloy reduced the variation in individual friction data points.

3. Passivation by preoxidation of ground surfaces reduced wear to 1/10, and friction was slightly more than one-half that for surfaces without preoxidation. Passivation of glass-bead-blasted surfaces increased friction and wear.

4. Friction and wear increased with the glass-bead blasting process when it was applied to the soft alloy vitallium.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, July 22, 1971,
114-03.

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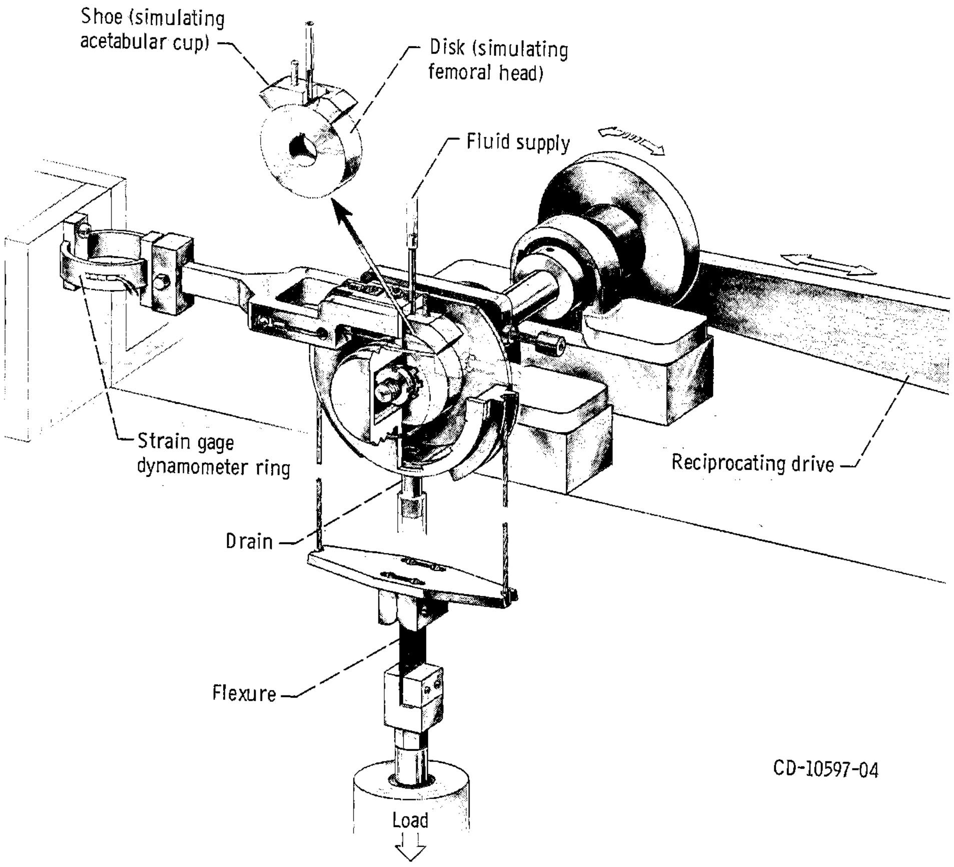


Figure 1. - Hip joint friction and wear apparatus.

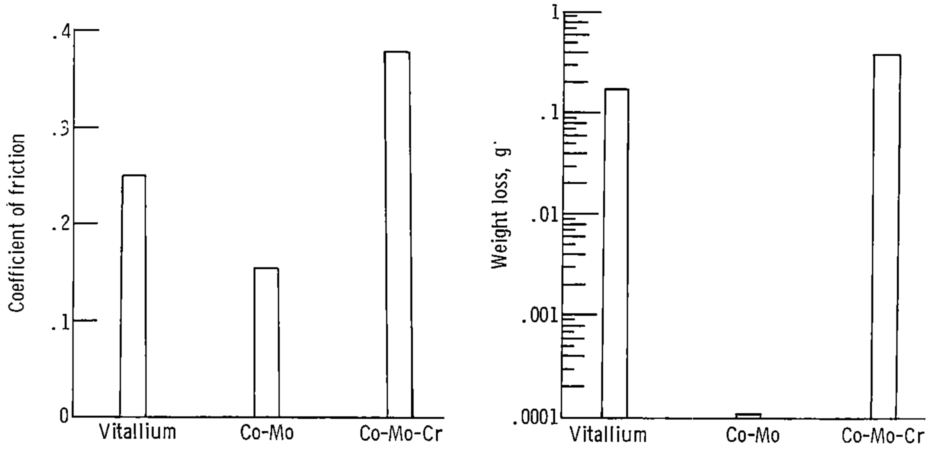
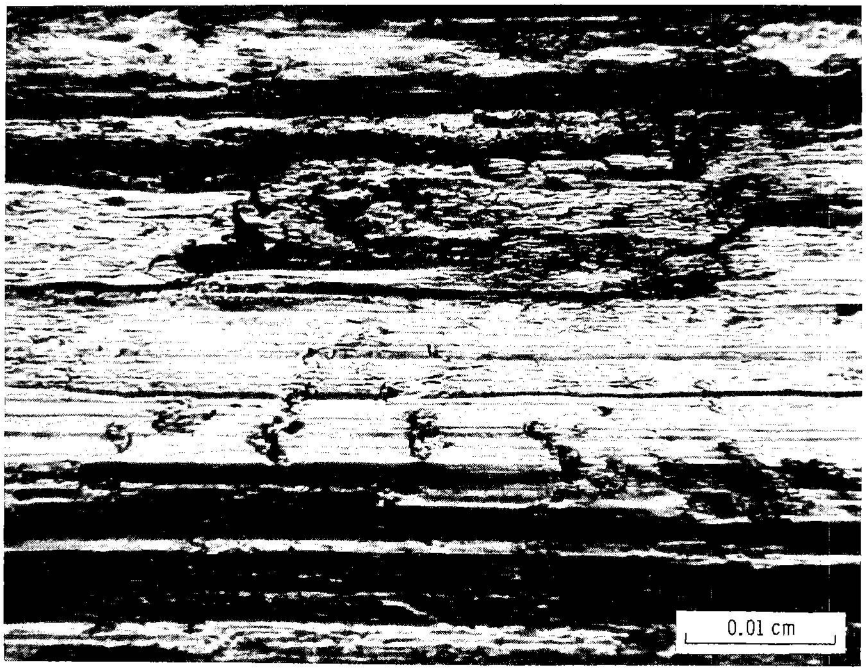
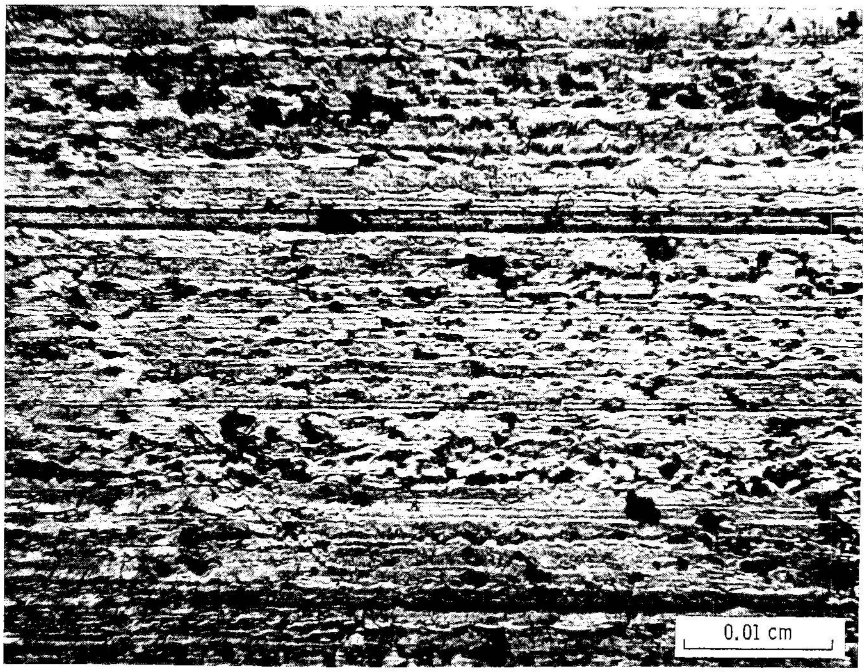


Figure 2. - Friction and wear of cobalt alloys with ground surface texture, run in heptane.

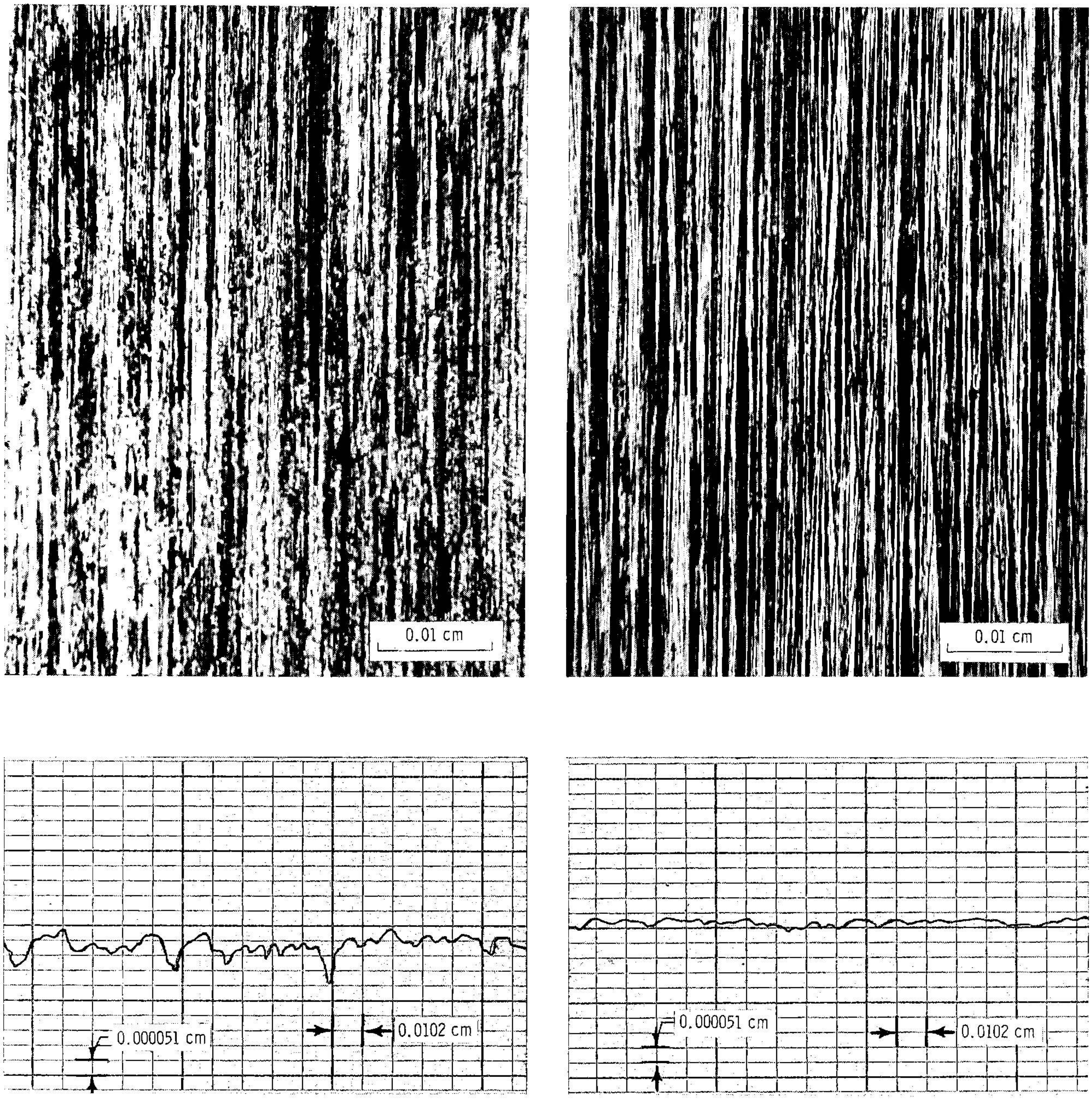


(a) Vitallium (cubic alloy).



(b) Cobalt-molybdenum (hexagonal alloy).

Figure 3. - Photomicrographs of wear tracks for cobalt alloy sliding surfaces run in heptane for 66 hours at 47.2 kilograms (104 lb) load oscillating at 0.97 hertz (58 cpm) with an angular displacement of 40 .



(a) Vitallium (cubic alloy).

(b) Cobalt-molybdenum (hexagonal alloy).

Figure 4. - Photomicrographs and surface profile traces of wear tracks for two cobalt alloys with ground surfaces.

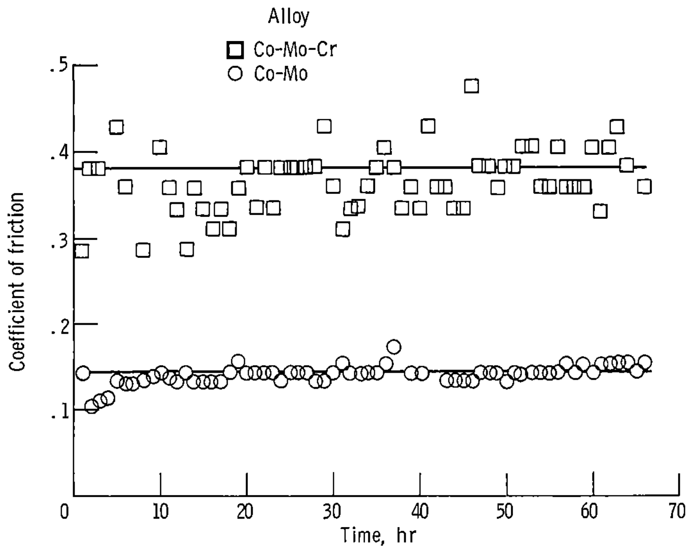
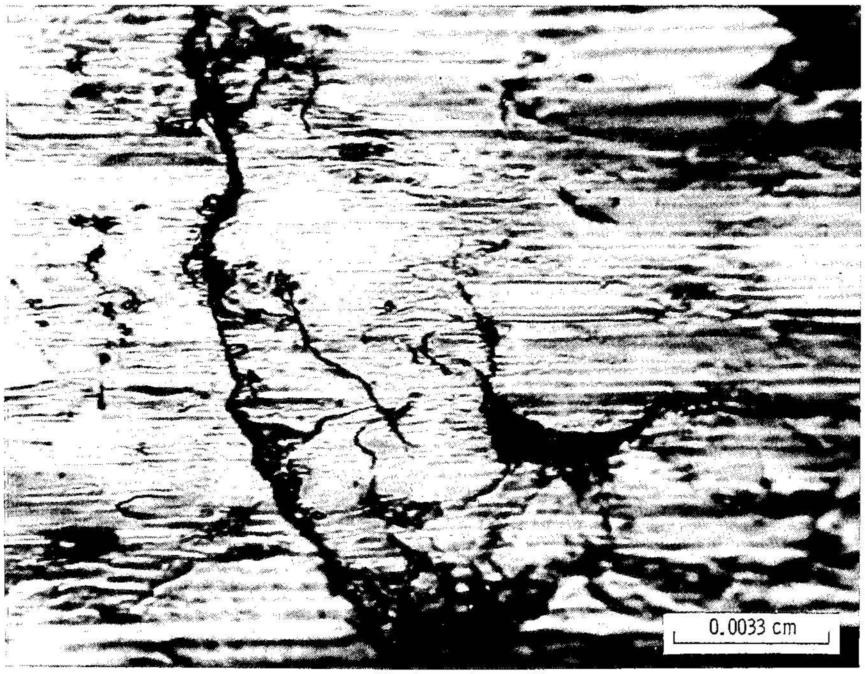
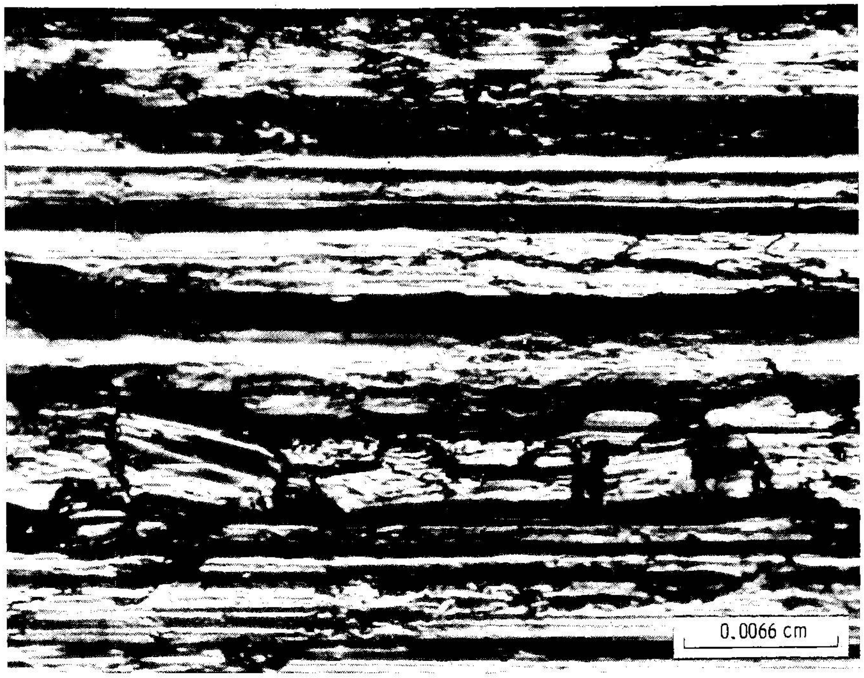


Figure 5. - Typical friction data for cobalt-molybdenum and cobalt-molybdenum-chromium alloys run in heptane with an argon atmosphere at 47.2-kilogram (104-lb) load and 0.97 hertz (58 cpm).

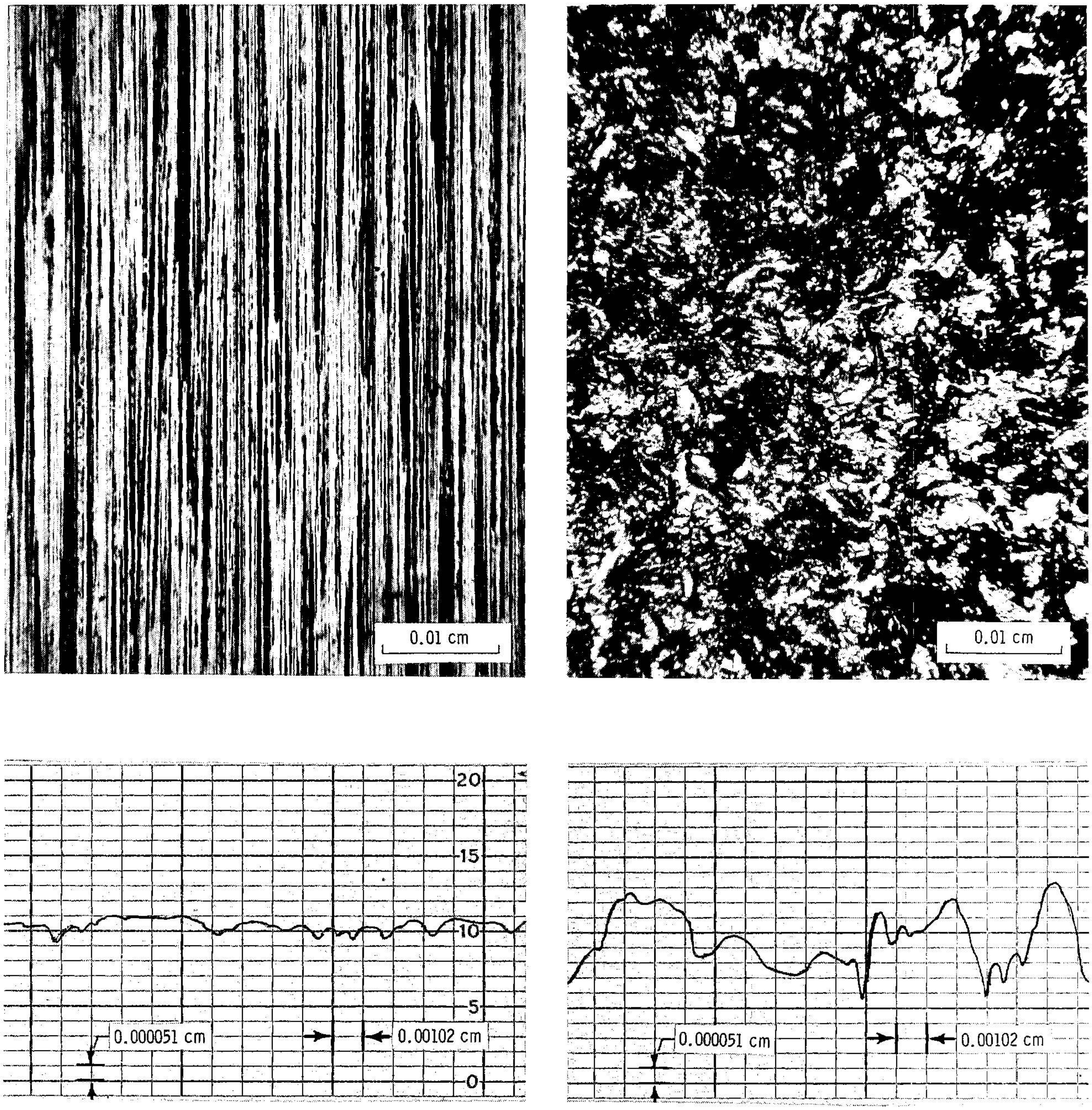


(a) Surface fracture.



(b) Fragmented surface.

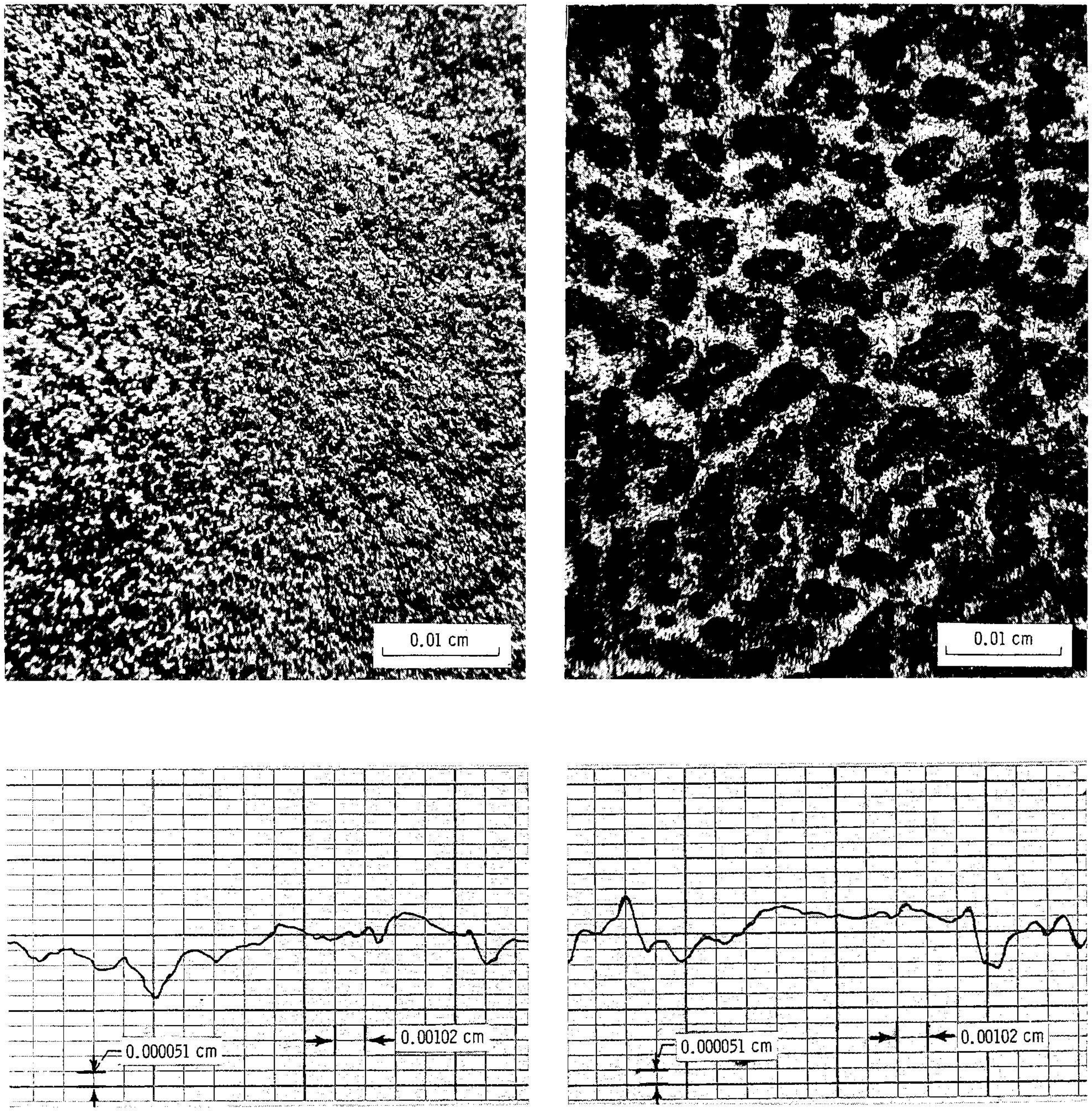
Figure 6. - Photomicrographs of wear tracks for cobalt-molybdenum-chromium alloy surfaces showing fractured and fragmented areas after operation.



(a) Ground surface.

(b) Grit-blasted surface.

Figure 7. - Photomicrographs and surface profile traces of wear tracks for cobalt- molybdenum-chromium alloy specimens with various surface textures.



(c) Al_2O_3-powder-and-water-vapor-blasted surface.

(d) Glass-bead-blasted surface.

Figure 7. - Concluded.

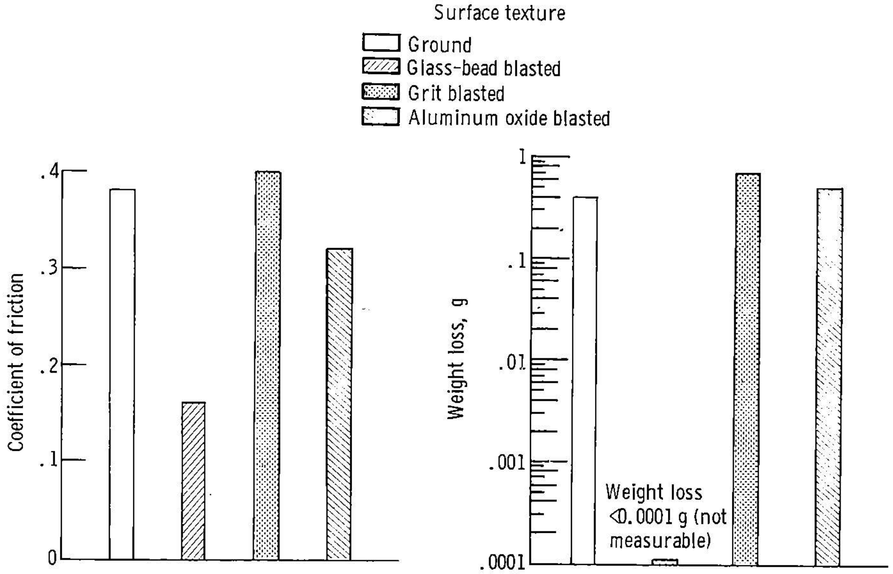


Figure 8. - Friction and wear of cobalt-molybdenum-chromium alloy with different surface texture, run in heptane.

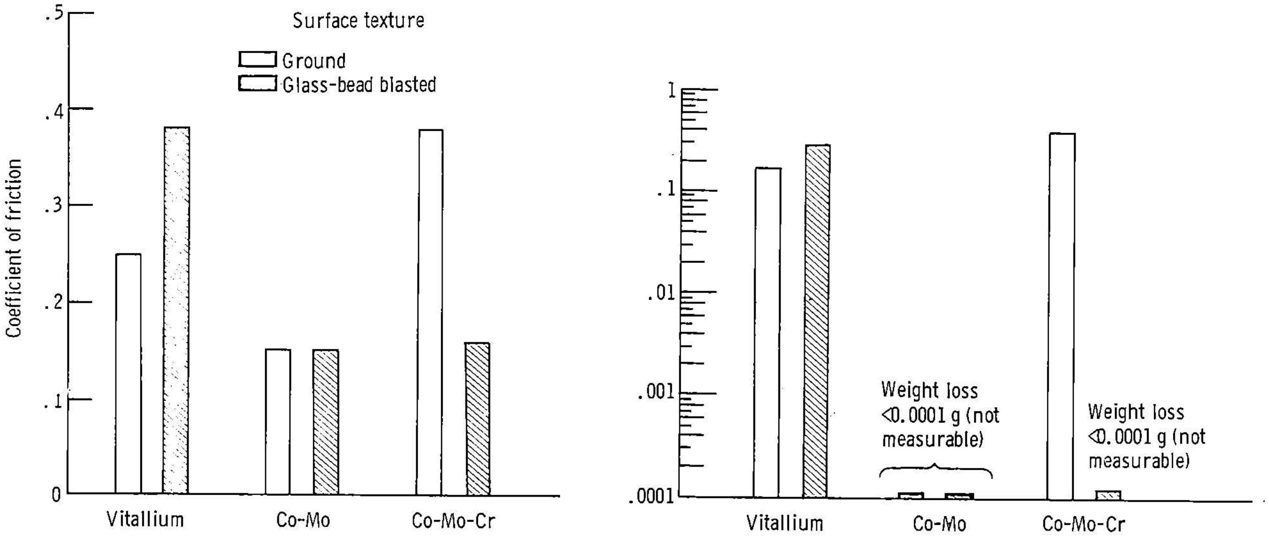


Figure 9. - Friction and wear of cobalt alloys with ground and glass-bead-blasted surface texture, run in heptane.

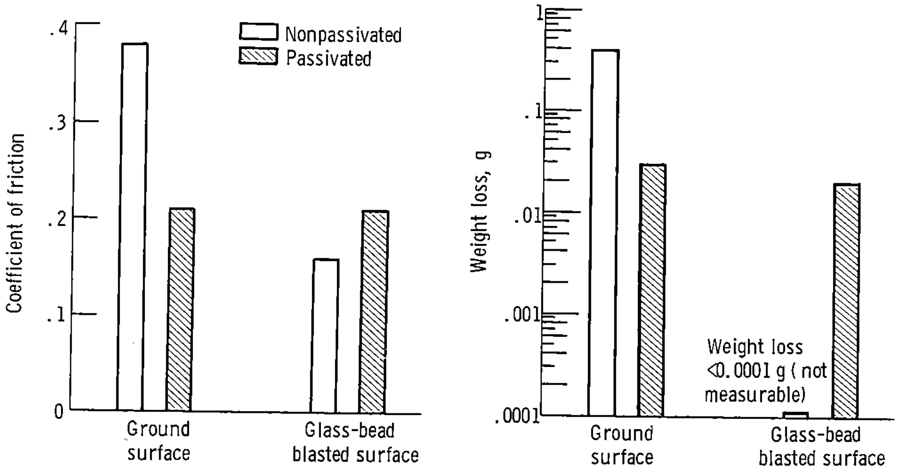


Figure 10. - Friction and wear of cobalt-molybdenum-chromium alloy with nonpassivated and passivated surfaces, run in heptane.

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