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LEAD, INDIUM, AND TIN AS POTENTIAL LUBRICANTS IN LIQUID HYDROGEN

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16. Abstract

Friction and wear experiments were conducted in liquid hydrogen using AISI 440 C riders in sliding contact with coated 440 C disks. These experiments revealed that thin coatings of lead, indium, or tin can function, for short times useful in rocket vehicles, as solid film lubricants in sliding contact. All three metal films lubricate by forming a transfer film on the mating surface which prevents welding or galling. Ion-plated coatings gave lower friction and better antigalling protection than the electroplated coating of the same metal. Lead gave the best results of the three metal coatings used.

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SUMMARY

Stainless steel (AISI 440 C) was run in sliding contact with lead, indium, and tin coatings on 440 C in liquid hydrogen to determine their lubricating capability. Also studied was the effect of coating thickness on the effective coating life and the effect of the method of applying the coating.

Experiments were conducted with a hemispherically tipped (4.76-mm rad) rider sliding against the flat surface of a coated 440 C steel disk submerged in liquid hydrogen. The load was 1 kilogram, and the sliding velocity was 12.4 meters per second (40.7 ft/sec).

These experiments revealed that thin coatings of lead, indium, or tin can function as solid lubricants for short periods of time useful in rocket vehicles. The lead coating showed the longest life of the three metals used in this investigation.

INTRODUCTION

Bearings and seals of rocket vehicles require lubricants that will operate in liquid hydrogen for short periods of time with high reliability. Some applications require the bearing to operate also in a radiation environment (while in the liquid hydrogen) and to function under cyclic operating conditions (up to 100 start-stop cycles). These applications require lubricants which are not used in conventional bearing applications. Since the duration of an operating cycle for rocket vehicle bearings and seals is relatively short (compared to conventional applications), the total operating life is measured in hours. This point is important when determining the value of a lubricant selected for this type of application.

Radiation resistance refers to the ability of a material to withstand radiation for given periods of time without a significant loss of physical properties. A material selected for a radiation application should not become excessively radioactive (e.g., a cobalt alloy should not be considered a candidate material). Polymers such as polytetrafluoroethylene (PTFE) and polytrifluorochloroethylene (PTFCE) which have been shown to have satisfactory cryogenic lubricating properties (refs. 1 and 2) do not have the necessary radiation resistance (refs. 3 and 4). Other polymers which possess better radiation resistance (polyimides, polybenzimidazole, and pyrrone) do not have the required lubricating or physical properties for cryogenic service (refs. 5 and 6).

The three metals selected for this investigation, lead, indium, and tin, have satisfactory cryogenic physical properties (refs. 7 and 8). Also of importance in the selection of a solid lubricant is its shear strength and transfer film forming tendency. Lead, indium, and tin are common components of conventional bearing materials, and at normal operating temperatures (20° to 200° C) all form transfer films on the mating rubbing or sliding surfaces.

The objectives of this study were to determine (1) the effectiveness of lead, indium, and tin coatings as solid film lubricants in liquid hydrogen and (2) the best method of applying the metal film to the substrate to achieve the longest life.

Experiments were conducted using a pin-on-disk apparatus with the coating applied to the disk and the specimens submerged in liquid hydrogen. Sliding velocity was 12.4 meters per second, and the load was 1 kilogram.

APPARATUS AND PROCEDURE

The apparatus used in the friction and wear studies is shown in figure 1. The basic elements consisted of a hemispherically tipped, 4.76-millimeter-radius rider specimen held in sliding contact with the flat surface of a 63.5-millimeter-diameter rotating disk. The experiments were conducted with specimens completely submerged in liquid hydrogen. The drive shaft supporting the disk specimen was driven by a hydraulic motor through a 6:1 speed increaser and provided a sliding velocity of 12.4 meters per second for the data reported herein. Helium-purged seals (not shown in fig. 1) were used to prevent air leakage in and cryogenic fluid leakage out around the drive shaft.

The rider specimen was loaded to 1 kilogram against the rotating disk specimen by a helium-pressurized bellows assembly. Load and frictional force were continuously measured by strain-gage dynamometer rings mounted inside the environmental chamber and recorded on a strip-chart recorder. The rider wear was determined by measuring the wear-scar diameter and calculating wear volume.

The test chamber was cleaned with 90 percent ethyl alcohol prior to each run to eliminate contaminants from previous runs or moisture. After the cleaning and installation of specimens, the test chamber was bolted in place and purged with helium gas to remove residual air and moisture and then filled with liquid hydrogen. After the test chamber was full and the liquid boiling stabilized, the rider specimen was loaded against

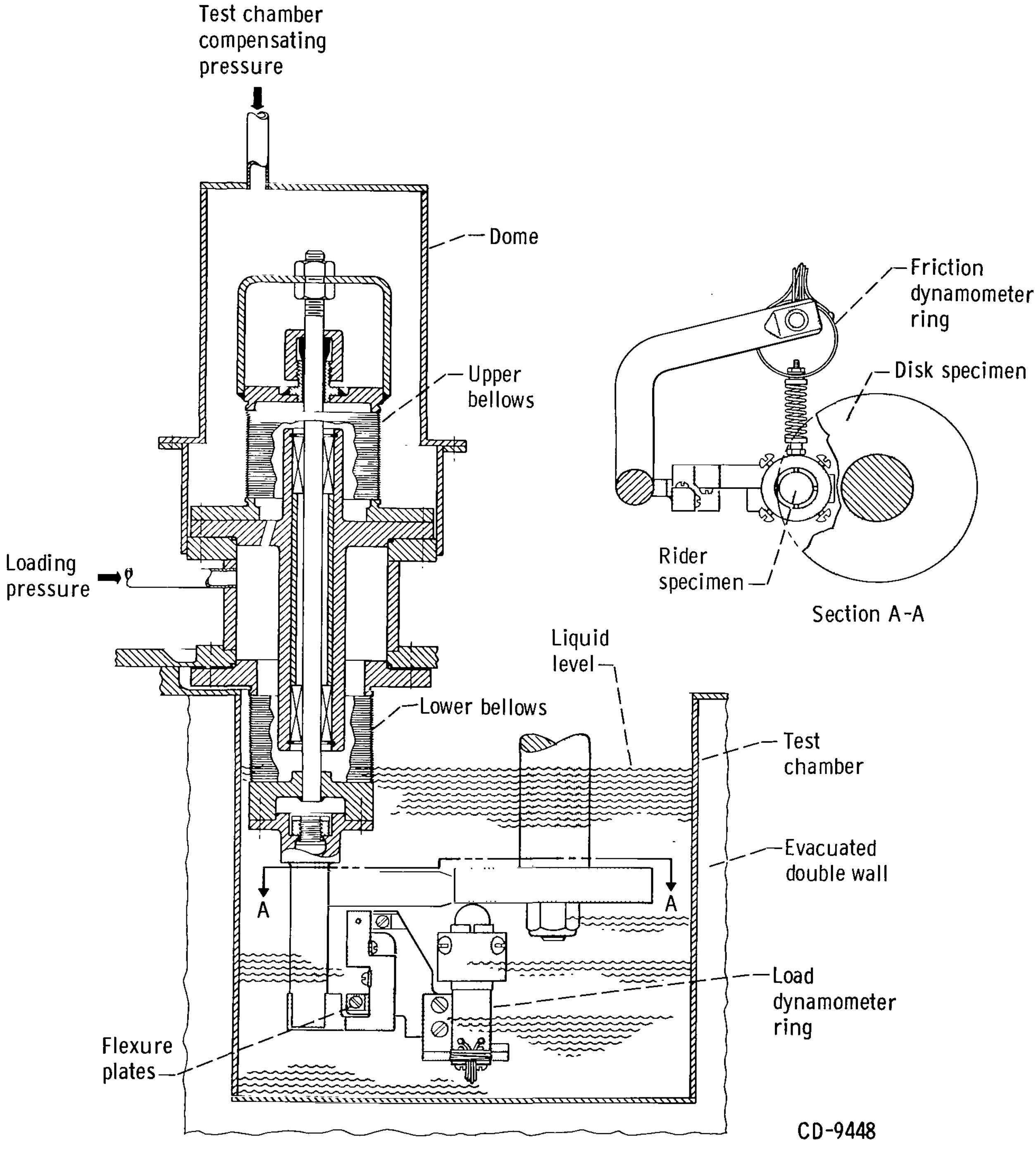


Figure 1. - Cryogenic fuel friction apparatus with specimen loading system.

the rotating disk. The duration of test runs was 2 to 60 minutes.

The surfaces of the metal rider specimens were prepared as follows: (1) ground to a root-mean-square finish of 10^{-1} micrometer (4 μin.), (2) scrubbed with moist levigated alumina, (3) washed in tap water, and (4) washed in distilled water and dried prior to the test.

RESULTS AND DISCUSSION

Electroplated Coatings

Lead. - Lead was electroplated to varying thicknesses on 440 C stainless-steel disks and run in sliding contact with AISI 440 C hemispherically tipped riders in liquid hydrogen. The sliding velocity of 12.4 meters per second (40.7 ft/sec) and the load of 1 kilogram were held constant for these experiments.

These results show that the 50-micrometer lead coating reduced the rider wear rate (fig. 2(a)) and the friction coefficient (fig. 2(b)) compared with the uncoated 440 C. The friction coefficient of uncoated 440 C on 440 C was 0.5 for the first 30 minutes and

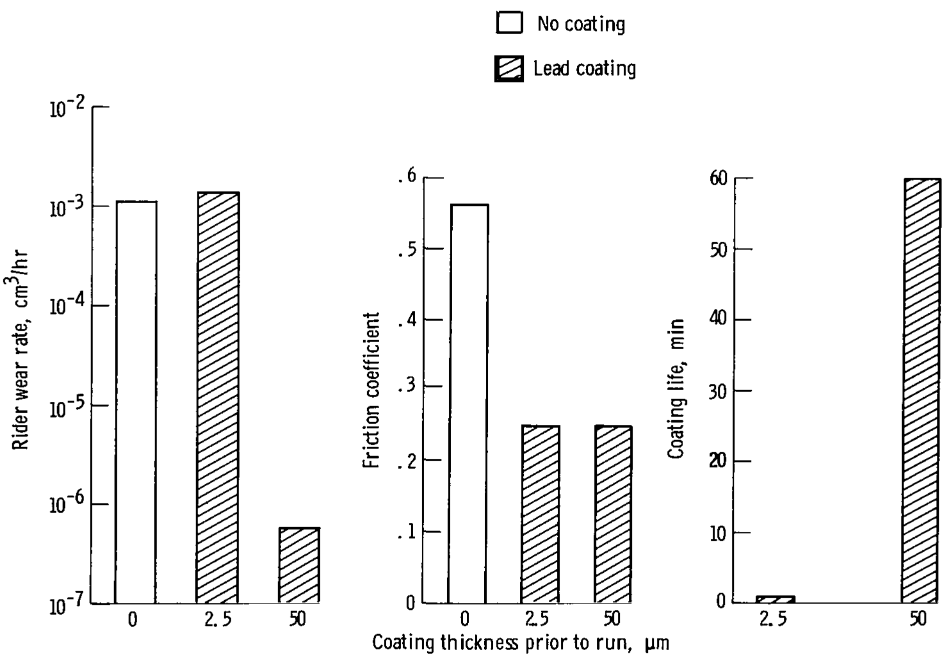
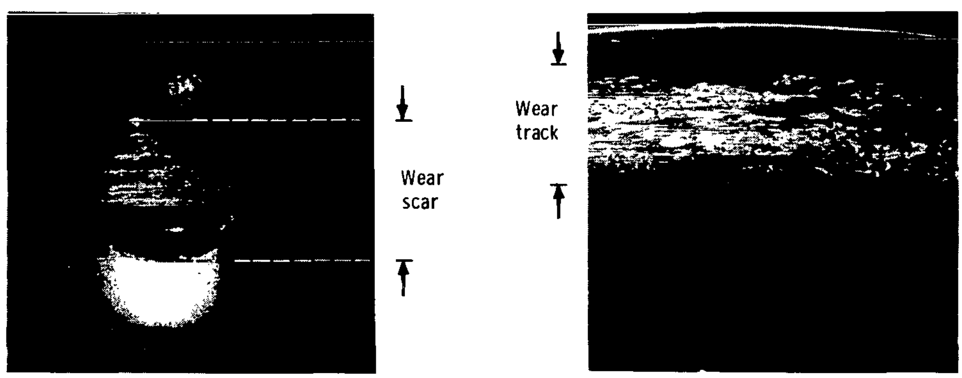


Figure 2. - Performance of 400 C riders in sliding contact with electroplated lead on 440 C disks in liquid hydrogen. Load, 1 kilogram; sliding velocity, 12.4 meters per second; hardness of 440 C. Rockwell C-56.

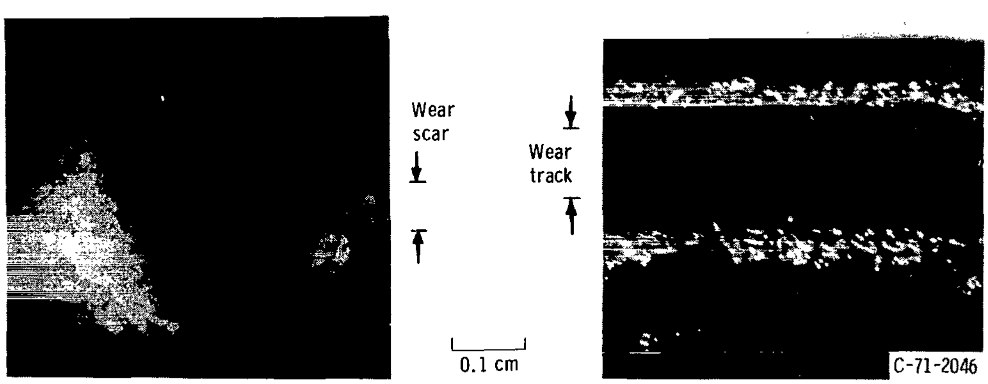
then gradually increased to 1 as the run was continued to 60 minutes; the friction coefficient for the lead-lubricated specimens was 0.25. Wear rate (fig. 2(a)) was reduced by a factor of over 1000 with the 50-micrometer-thick coating. Figure 2(c) shows a coating life comparison for the 2.5-and 50-micrometer thicknesses. (Coating life was defined as that point when an appreciable change in friction indicated that the coating was worn through.) Note that the life of the thicker coating (50 μm) was 60 minutes. Figure 3(a) shows photographs of the wear surfaces for 440 C on 440 C which indicate gross welding and galling. As a comparison, figure 3(b) shows the wear surfaces for 440 C after sliding on a 50-micrometer lead coating; these photographs indicate the low rider wear and good condition of the disk surface.

Indium. - Figure 4 shows the results obtained with a 12-micrometer-thick indium coating on 440 C sliding against a 440 C rider; for comparison, results for no coating



Rider Disk

(a) 440 C rider and disk.



Rider Disk

(b) 440 C rider and electroplated lead-coated 440 C disk.

Figure 3. - Wear on 440 C riders and uncoated and electroplated lead-coated 440 C disks after running in liquid hydrogen. Sliding velocity, 12.4 meters per second; load, 1 kilogram; duration of run, 60 minutes; thickness of coatings, 50 micrometers; hardness of 440 C disks and riders, Rockwell C-56.

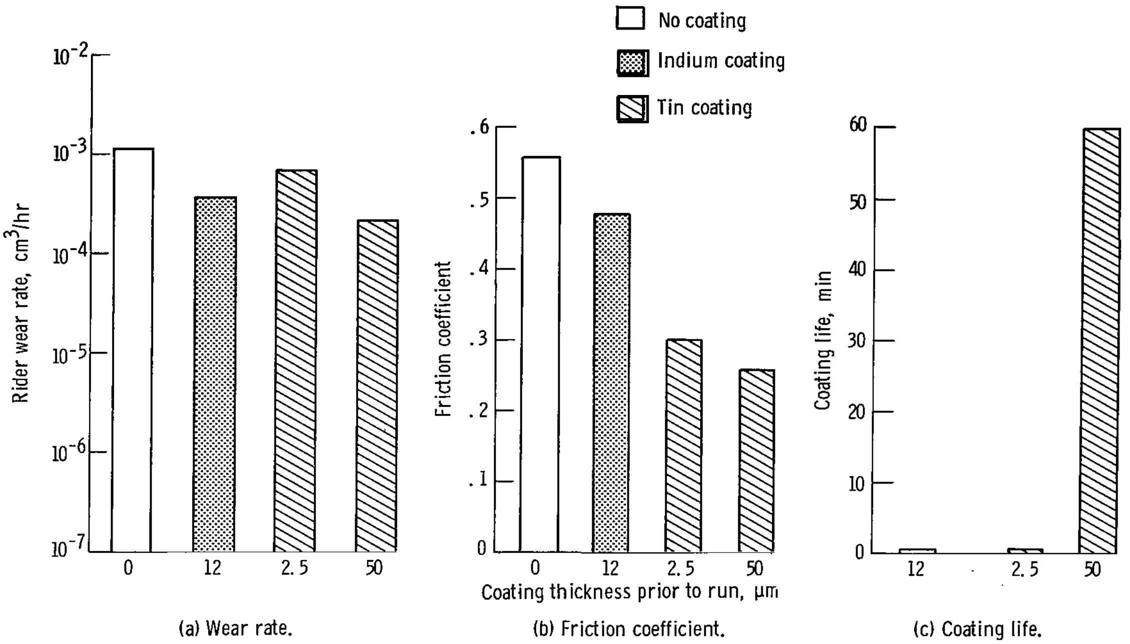


Figure 4. - Performance of 440 C riders in sliding contact with electroplated indium or tin on 440 C disks, in liquid hydrogen. Load, 1 kilogram; sliding velocity, 12.4 meters per second; hardness of 440 C, Rockwell C-56.

and two tin coatings are also shown. Only one thickness of indium coating was run. The experiment indicated that, although the sliding surfaces were protected from galling by a transfer film, the indium was too soft to be usable under these test conditions. Cold flowing of the indium coating was evident on the disk surface. Friction coefficient and wear rate were not significantly reduced by the indium coating; coating life was very short (1 min).

Tin. - Results obtained running 440 C riders in sliding contact with electroplated tin are shown in figure 4. Friction coefficient is considerably lower than that for bare 440 C on 440 C. Wear rate was not significantly reduced by the tin coating, although a transfer film of tin was formed on the rider. Examination of the tin coatings indicated that the tin adjacent to the wear track (on the disk) had fine perpendicular cracks with some pieces chipped off outside the track area. This was not observed with the lead or the indium coatings. Photographs of the wear surfaces of the electroplated tin coatings are shown in figure 5. Friction coefficient with the tin coatings was about one-half of that for bare 440 C.

Thickness of electroplated coatings. - For lead films, the thickness of the coating had a greater effect on the wear rate than on the friction coefficient. With a thickness of 50 micrometers, a considerable reduction in wear was obtained. Examination of all coatings studied revealed that the thinner coatings became nonadherent to the substrate, whereas the thick (50-μm) coatings showed better adherence. This indicated that wear

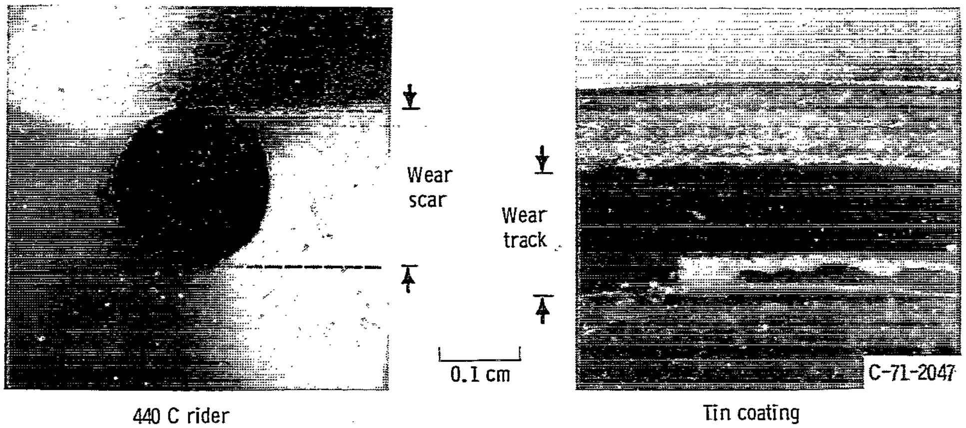
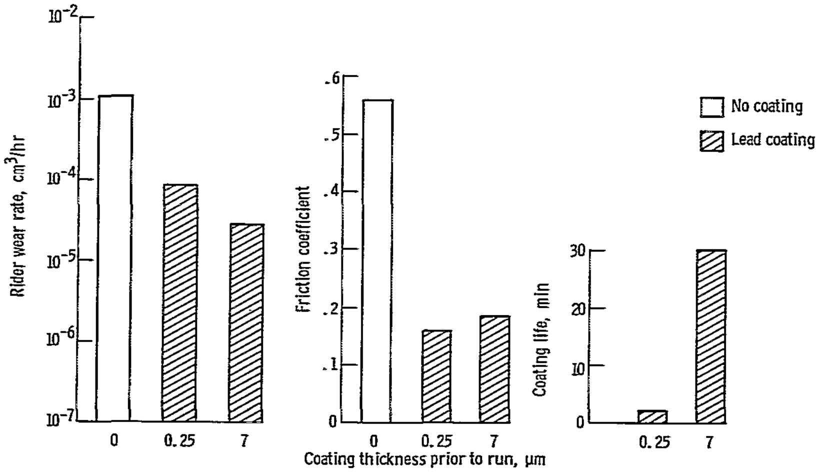


Figure 5. - Electroplated tin on 440 C disk with respective rider wear scar after running in liquid hydrogen. Sliding velocity, 12.4 meters per second; load, 1 kilogram; duration of run, 60 minutes; thickness of coating, 50 micrometers; hardness of 440 C disk and rider, Rockwell C-56.

(and coating life) was a function of coating adherence as well as of coating thickness. Data in reference 9 indicate that, when coatings were applied by ion plating, a considerable improvement in life (at room temperature) was obtained as well as a reduction in the friction coefficient. Lead and indium were applied to 440 C disks by ion plating to determine if an improvement in lubricating characteristics would be obtained under the conditions of these experiments.

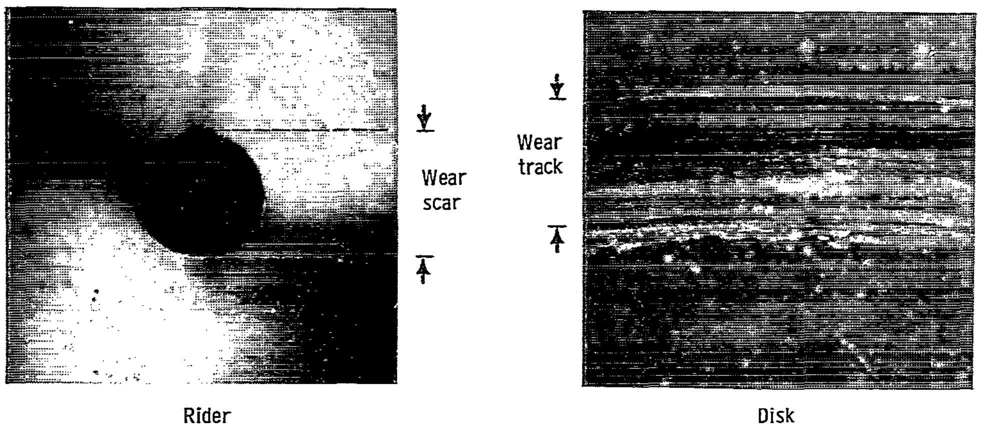
Ion-Plated Coatings

Lead. - Figure 6 shows the results obtained with ion-plated lead. Test results indicated that the ion-plated coatings did not fail from poor adherence but from penetration of the coating by the rider. After coating failure, wear rate increases but friction coefficient is essentially unaffected. Figure 6 also shows that lower wear and longer life can be obtained with ion platings. Compare the wear (fig. 6(a)) of the 0.25-micrometer ion-plated lead with the 2.5-micrometer electroplated lead (fig. 2(a)); wear rate is less by a factor of 10. By increasing the thickness of the ion-plated lead to 7 micrometers, a tenfold increase in life is obtained compared with the 0.25-micrometer ion-plated lead or the 2.5-micrometer electroplated lead. Friction coefficients of the ion-plated lead coatings were less than those for the electroplated lead.

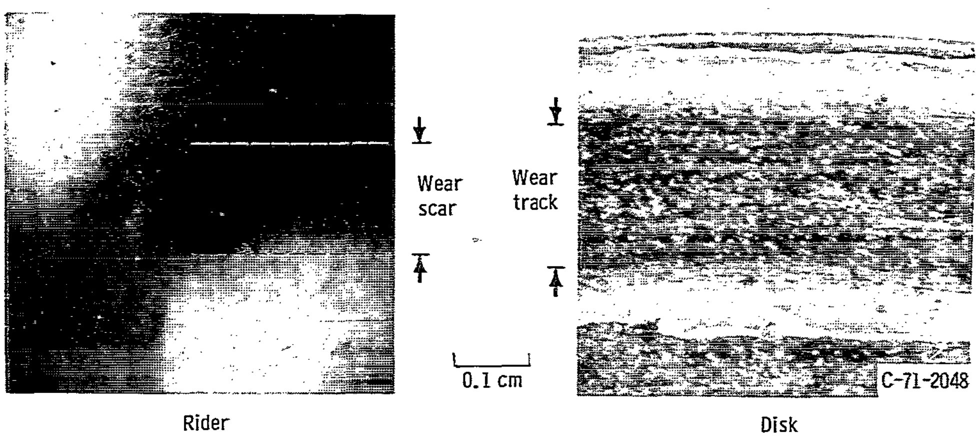


(a) Wear rate. (b) Friction coefficient. (c) Coating life.

Figure 6. - Performance of 440 C riders in sliding contact with ion-plated lead on 440 C disks in liquid hydrogen. Load, 1 kilogram; sliding velocity, 12.4 meters per second; hardness of 440 C, Rockwell C-56.



(a) 440 C rider and ion-plated lead-coated 440 C disk; duration of run, 29 minutes.



(b) 440 C rider and ion-plated indium-coated 440 C disk; duration of run, 15 minutes.

Figure 7. - Wear on 440 C riders and ion-plated lead- and indium-coated 440 C disks after running in liquid hydrogen. Sliding velocity, 12.4 meters per second; load, 1 kilogram; thickness of coatings, 7 micrometers; hardness of 440 C disks and riders, Rockwell C-58.

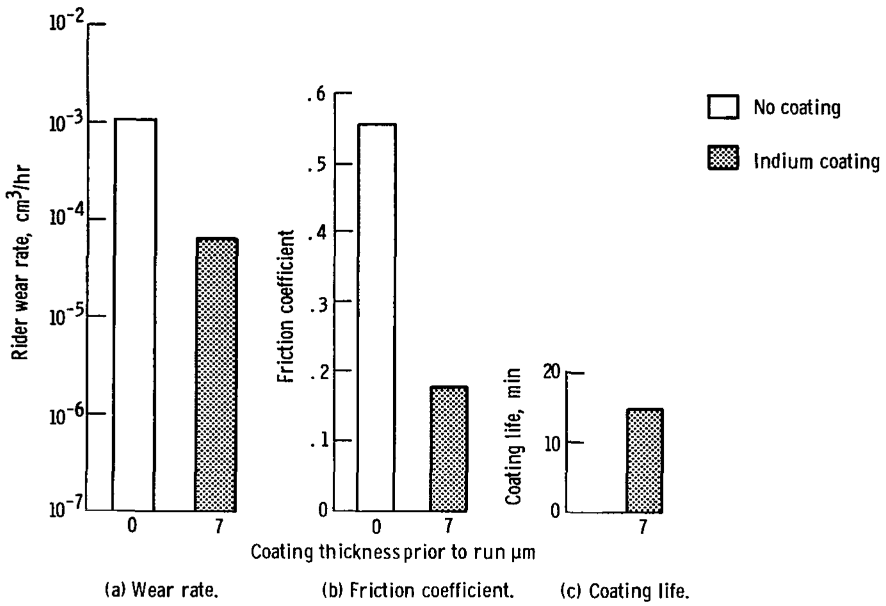


Figure 8. - Performance of 440 C riders in sliding contact with ion-plated indium on 440 C disks in liquid hydrogen. Load, 1 kilogram; sliding velocity, 12.4 meters per second; hardness of 440 C, Rockwell C-56.

Photographs of typical wear surfaces are shown in figure 7(a). No gross welding is evident, but wear is greater than that obtained for the 50-micrometer electroplated lead coating (fig. 3(b)).

Indium. - Wear rate, friction coefficient, and life of ion-plated indium are shown in figure 8. A comparison of the 7-micrometer ion-plated indium with the 12-micrometer electroplated indium (fig. 4(a)) shows an improvement in wear rate by a factor of 7 and an improvement in life (fig. 4(c)) by a factor of 10 with the ion plating. Friction coefficient was also lower with the ion plating. Photographs of the wear surfaces are shown in figure 7(b).

SUMMARY OF RESULTS

Sliding-contact experiments with AISI 440 C riders against lead, tin, and indium coatings on 440 C disks in liquid hydrogen gave the following results:

1. Lead, tin, and indium coatings lubricate in liquid hydrogen. All three metal coatings showed transfer films (to the rider) which prevented galling of the sliding surfaces. The lead coatings gave the best results of the three metal coatings used.

2. Ion plating the metal coating onto the 440 C substrate (instead of electroplating) provided a coating with better adherence and better protection of the substrate against galling.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, May 27, 1971,
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