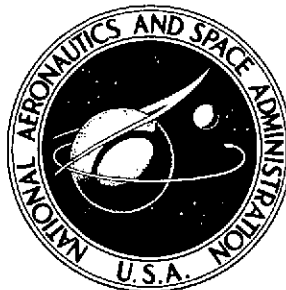
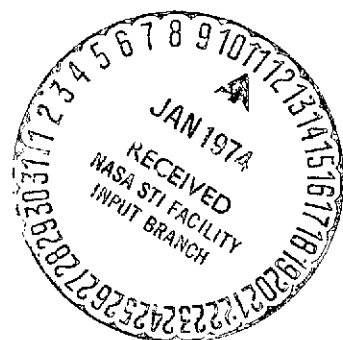


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FRICION BEHAVIOR OF GLASS AND METALS IN CONTACT WITH GLASS IN VARIOUS ENVIRONMENTS

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16. Abstract Sliding friction experiments have been conducted for heat-resistant glass and metals in contact with glass. These experiments were conducted in various environments including vacuum, moist air, dry air, octane, and stearic acid in hexadecane. Glass exhibited a higher friction force in moist air than it did in vacuum when in sliding contact with itself. The metals, aluminum, iron, and gold, all exhibited the same friction coefficient when sliding on glass in vacuum as glass sliding on glass. Gold-to-glass contacts were extremely sensitive to the environment despite the relative chemical inertness of gold.			
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SUMMARY

An investigation was conducted to determine the effect of environment on the friction characteristics of glass in sliding contact with heat-resistant glass and three metals in sliding contact with glass. The metals were aluminum, iron, and gold. The environments included vacuum, moist air, dry air, octane, and a lubricant, stearic acid in hexadecane. A hemispherical rider specimen of glass or metal slid on a glass disk.

Results of the study indicate that, unlike all other materials examined, glass exhibits a lower friction force in vacuum than in air. The three metals examined in contact with glass all give friction forces comparable to those for glass-to-glass contacts in vacuum. These results occur because glass transfers to the metals, and glass is essentially sliding on itself. Gold in contact with glass is extremely environment sensitive in its friction behavior.

INTRODUCTION

In most practical lubrication systems, metal alloys are in sliding, rolling, or rubbing contact with metal alloys. There are other classes of solid materials which are also used. These include polymers, carbons, ceramics, and glasses. Glasses have been examined in lubrication systems, particularly as high-temperature coatings (refs. 1 to 3).

Glasses, like ceramic materials and unlike metals, are extremely sensitive in their mechanical behavior to surface films (ref. 4). Ordinary atmospheric moisture can cause a measurable reduction in the strength of glasses (ref. 5). This surface film and its sensitivity to mechanical behavior may exert an influence on adhesion, friction, and wear.

Glass surfaces are frequently in contact with metals. The contribution of each member of such couples to adhesion, friction, and wear is of interest.

The objective of this investigation was to examine the influence of surface films on the adhesion, friction, and wear of glass in sliding contact with glass and in contact with various metals. Experiments were conducted in vacuum, air, and two lubricant films, octane and stearic acid in hexadecane. Sliding friction studies were conducted with a hemispherical rider contacting a flat disk. Friction force was measured as a function of load and ambient pressure.

MATERIALS

Heat-resistant glass was used in all friction experiments. The metals, iron, aluminum, and gold, were 99.99 percent pure.

The glass specimens had fire-polished surfaces. The metal specimens were polished with metallurgical papers down to 600 grit and were then polished with 3-micrometer-diamond paste to produce a mirrorlike surface.

EXPERIMENTAL APPARATUS AND PROCEDURE

Specimens

The friction specimens consisted of a glass disk specimen 6.5 centimeters in diameter and 1.2 centimeters thick and a hemispherical rider (either glass or metal) with a 0.5-centimeter radius. A schematic diagram of the specimens and the apparatus is shown in figure 1. The disk is mounted on a drive shaft which is rotated with a magnetic drive assembly. The drive assembly provides rotation at various speeds (held constant in this study, at 30 cm/min). The rider is mounted in a holder to one end of a stainless-steel shaft. Sliding experiments are conducted with the rider loaded against the disk, which in this study was always glass. The riders were either glass or metal. As the disk is rotated, the rider scribes a circular wear track on the flat surface of the disk. The loads used in this investigation varied from 100 to 1000 grams, and the temperature was 23° C.

Experimental Chamber

The experiments are conducted in the chamber shown in figure 1. For those experiments conducted in vacuum, the system is pumped by sorption pumps and an ion

pump. Pressure in the system is read with a cold-cathode ionization gage. The vacuum system achieved a pressure of 10^{-10} torr after bakeout at 250° C.

For those experiments conducted in air saturated with water vapor, the system was bled to atmospheric pressure from 10^{-10} torr. The lubricant films, octane and stearic acid in hexadecane, were applied by placing a few drops of the fluid on the surface.

Measurements

The friction force between the disk and rider specimens is continuously recorded on a strip chart during friction experiments. The beam which contains the rider specimen is welded into a bellows assembly which is gimbal mounted to the vacuum system. The gimbal mounting permits deadweight loading of the rider against the disk surface (fig. 1). At right angles to the deadweight loading, the beam containing the rider can move in two directions in the horizontal plane. Movement of the rider (with the disk as it rotates) is restrained by a cable which is attached to a beryllium-copper ring. The ring contains four sets of strain gages measure the frictional force between the disk and rider specimens.

RESULTS AND DISCUSSION

The load or force with which two glass surfaces are pressed into contact affects the real contact area and corresponding friction force. This is demonstrated in the data of figure 2. In figure 2 the friction force for glass sliding on glass is presented as a function of load in two environments, air saturated with water vapor and a vacuum of 10^{-10} torr. The friction force is proportional to load in both environments. Figure 1 indicates that the basic law of friction relating friction force to load applies to glass as well as other materials. The friction coefficient is independent of the applied load.

The friction force is proportional to load not only for glass sliding on glass but also for metals sliding on glass. In figure 3, friction force is plotted as a function of load for aluminum sliding on glass in vacuum. A comparison of the slopes obtained from figures 2 and 3 indicates that the coefficients of friction are approximately the same for glass sliding on glass and aluminum sliding on glass. Similar friction results have been obtained with other metals such as iron and gold sliding on glass. These results are discussed in the section Environmental Effects.

The similar behavior for glass sliding on glass and metals sliding on glass is explained by an examination of the surfaces after sliding. The glass disk surface undergoes wear for both metals sliding on glass and for glass sliding on glass. Microscopic

examination of the metal surface after sliding indicates the transfer of glass and its embedment in the metal surface. Thus, the metal surface becomes charged with glass, and ultimately glass is sliding on glass.

Initially, with metals in contact with clean glass, adhesion of the metal to the glass occurs. With tangential motion associated with these experiments, fracture takes place in the glass. Both the interfacial adhesive bond and the shear strength of the aluminum are greater than the force necessary to fracture glass.

The resulting effect is that glass transfers to the metal. What would appear to be an abrasive wear process from an examination of only the glass surface, in fact, involves adhesive wear.

Increasing the load influences friction behavior. Other mechanical parameters including the speed with which sliding occurs also affect the friction behavior.

Environmental Effects

Most materials are extremely sensitive to the environment; in their adhesion, friction, and wear behavior glasses are no exception. In figure 2 friction force is presented for glass sliding on glass in a vacuum of 10^{-10} torr and in moist air saturated with water. A marked difference in friction behavior exists in the two environments. With the 1000-gram load the friction force in vacuum (10^{-10} torr) is one-half the value obtained in moist air (760 torr).

The results presented in figure 2 indicate that environment does affect friction force. The results, however, are unusual in that generally for most materials adhesion, friction, and wear are greater in a vacuum environment. This is the case with metals, carbons, and ceramics.

In figure 4 the coefficient of friction (friction force divided by the normal load) is plotted as a function of ambient pressure for glass sliding on glass. From a pressure of 10^{-10} torr to 1 torr friction coefficient remained unaffected. At pressures above 1 torr, the coefficient of friction increased from 0.5 to 1.0.

The anomalous behavior of glass with respect to friction can be explained on the basis of increased adhesion of glass in the presence of water vapor. Adsorbed water increases the adhesion force. For example, the adhesive force for glass in the presence of water is more than three times what it is for glass in the presence of octane (ref. 6).

The interaction of a metal (aluminum) with a glass surface during sliding has already been discussed. The coefficient of friction results of figure 3 and figure 2 were similar because of the observed transfer of glass to an aluminum surface during sliding in vacuum. Such transfer behavior implied interfacial adhesion of the glass to the

aluminum. Studies with ionic crystalline solids containing oxygen (e. g., Al_2O_3) and contacted by metals indicated that adhesion was the result of interfacial chemical bonding of the metal to the oxygen-containing surface (ref. 7). In order to determine if a similar mechanism exists for metals in contact with glasses, friction experiments were conducted with iron and gold contacting glass.

Iron was selected because it bonds chemically to the oxygen of aluminum oxide and the result is strong adhesion and high friction (ref. 7). In contrast, gold was selected because in reference 7 it gave evidence of no chemical bonding, poor adhesion, and correspondingly low friction when in contact with glass.

The friction forces measured at various loads for iron and gold in contact with glass in vacuum are presented in figures 5 and 6, respectively. With both metals the results were nearly identical to those obtained with aluminum in contact with glass and to those for glass in contact with glass. All three metals had glass particles transferred to their surface.

When metals are in sliding or rubbing contact with glass in air at atmospheric pressure and when the air contains moisture, metals transfer to glass (ref. 8). Friction coefficients under such conditions are typically from 0.5 to 0.7, depending on the shear properties of the metal involved. With metals sliding on glass in a vacuum (figs. 3, 5, and 6) glass transfers to the metal. Friction coefficients are approximately 0.5. Thus, while the friction coefficients are not markedly different in the two cases, the mechanism is.

The difference in transfer characteristics in the two environments rests within the fracture properties of glass. The fracture behavior of glass is strongly affected by water (ref. 4). Water impedes fracture and is a manifestation of the Joffe effect in an amorphous solid. The Joffe effect involves the dissolution of surface microcracks and the resulting strengthening of the material. From the transfer characteristics observed with metals sliding on glass, it must be concluded that the fracture strength of glass increases in the presence of water vapor.

The friction results of figure 6 are interesting in that gold does not form stable oxides, and thus interfacial chemical bonding would appear unlikely. Notwithstanding this fact, bonding does occur because glass is found present on the gold surface after sliding. Further, the friction coefficient in vacuum is essentially the same as that observed with iron and aluminum.

It is extremely easy to develop fracture cracks in a glass surface. Simply dropping grains of sand on a glass surface from a few inches above that surface is sufficient to produce cracks (ref. 9). The concentrated stresses produced by the action of sliding under a normal load are sufficient to generate cracks in the glass surface. Fracture in glass invariably starts at the free surface (ref. 10). Thus, interfacial bonding forces associated with metal surface chemistry do not play the same role with glasses as they do for those same metals in contact with crystalline ionic solids.

In reference 7, with gold in contact with sapphire, there was an absence of any surface fracture cracks and no evidence of the transfer of sapphire to gold. With those metals which form strong chemical bonds (e. g., iron and aluminum), sapphire was found transferred to the metal. Sapphire, however, is much more resistant to brittle fracture than are glasses. Thus, with glasses, even the relatively weak van der Waals forces may be sufficient to retain glass on the gold surface once fracture has occurred in the glass because of mechanical stresses: Glass in this study was seen adhered to the gold surface. The particles were pyramidal in shape with the base of the pyramid bonded to the gold.

The effect of lubricant films on the friction and wear behavior of glass in contact with glass has been studied (ref. 11). As with metals, friction behavior is strongly dependent upon the lubricant used. With metals contacting glass, the lubrication mechanism is not clearly understood.

In figure 7 friction results are presented for iron and gold sliding on glass in the presence of an octane film. Octane readily adsorbs to iron but not to gold. With the 1000-gram load, the friction with iron is one-half that obtained with gold sliding on glass. It is the chemical affinity of iron for octane which accounts for these results.

Effect of Surface Films

The friction behavior of gold with glass is extremely sensitive to the nature of the surface film. Figure 8 presents friction data for gold sliding on glass with an octane film which is allowed to evaporate. The experiment was conducted in ordinary laboratory air (approximately 30 percent relative humidity). With the octane film present, the friction coefficient was 0.4. When the film was allowed to evaporate, the friction coefficient decreased to 0.2. Reapplication of octane to the surface resulted in an immediate increase in friction coefficient. Subsequent evaporation resulted in a return to a friction coefficient of 0.2. The same experiment performed in dry air did not yield the low friction coefficients observed in figure 8 with the evaporation of octane.

Gold does not interact with octane. Thus, the octane acts as an inerting environment allowing strong adhesion to develop between the glass disk and the gold rider. Moisture in air causes the decrease in friction shown in figure 8 when the octane evaporates.

The effect of moisture on metal-to-glass contacts is very unlike its effect upon glass-to-glass contacts. In figure 2 moisture produced an increase in friction coefficient for glass-to-glass contacts. As discussed in reference to figure 6, as a result of adhesion glass transfers to the gold surface in vacuum, so that glass is sliding on glass. The resistance of glass to fracture is increased by the presence of moisture, and its

friction coefficient is accordingly increased; therefore, the results of figure 8 are explained on the basis of reduced adhesion of gold to glass. Adsorbed water generally reduces the adhesion of most metals to themselves and other solids as well. With weaker interfacial bonds between the gold and glass, a greater portion of the friction force is represented by the shear of interfacial metal-to-glass bonds and less by the fracture of glass bonds.

The influence of surface films on the interaction of metals with glass is further demonstrated by the data of figure 9. In figure 9 friction coefficients are presented for gold and iron sliding on glass in the presence of stearic acid in hexadecane. Stearic acid is responsible for low friction forces presented in figure 9. Similar experiments with hexadecane alone resulted in friction coefficients in excess of 0.3.

The lubricant, stearic acid, is also very effective in reducing the friction for glass-to-glass contacts. With a thin solid film of stearic acid on a glass plate, reference 12 reports a friction coefficient of 0.035. This is markedly less than that calculated from the friction force presented in figure 9 (0.10) for glass and iron in contact with glass.

In figure 9 the friction force measured for gold-to-glass contact is consistently higher than the values obtained for the iron-to-glass contact. Stearic acid interacts with iron to form iron stearate. Gold does not form a stable stearate. This can account for the friction force differences seen in figure 9 with these two metals.

CONCLUSIONS

Based upon the friction results obtained in an investigation of glass-to-glass and metal-to-glass contacts in various environments, the following conclusions are drawn:

1. The friction force for glass in sliding contact with glass in vacuum is one-half of the value attained in moist air. Moisture in air causes an increase in adhesion and surface strengthening of glass. These changes result in an increase in friction. Glass is the only material known to exhibit lower friction in vacuum than in air.

2. Metals in contact with glass in vacuum exhibit the same friction behavior as glass in contact with glass. Because glass transfers to metals (e.g., aluminum, iron, and gold), glass is essentially sliding on itself. In moist air metal frequently transfers to glass.

3. Gold-to-glass contacts are extremely sensitive to changes in environment. Sliding in octane (inert environment) produces twice the friction coefficient observed for that same couple in moist air.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, September 19, 1973,
502-01.

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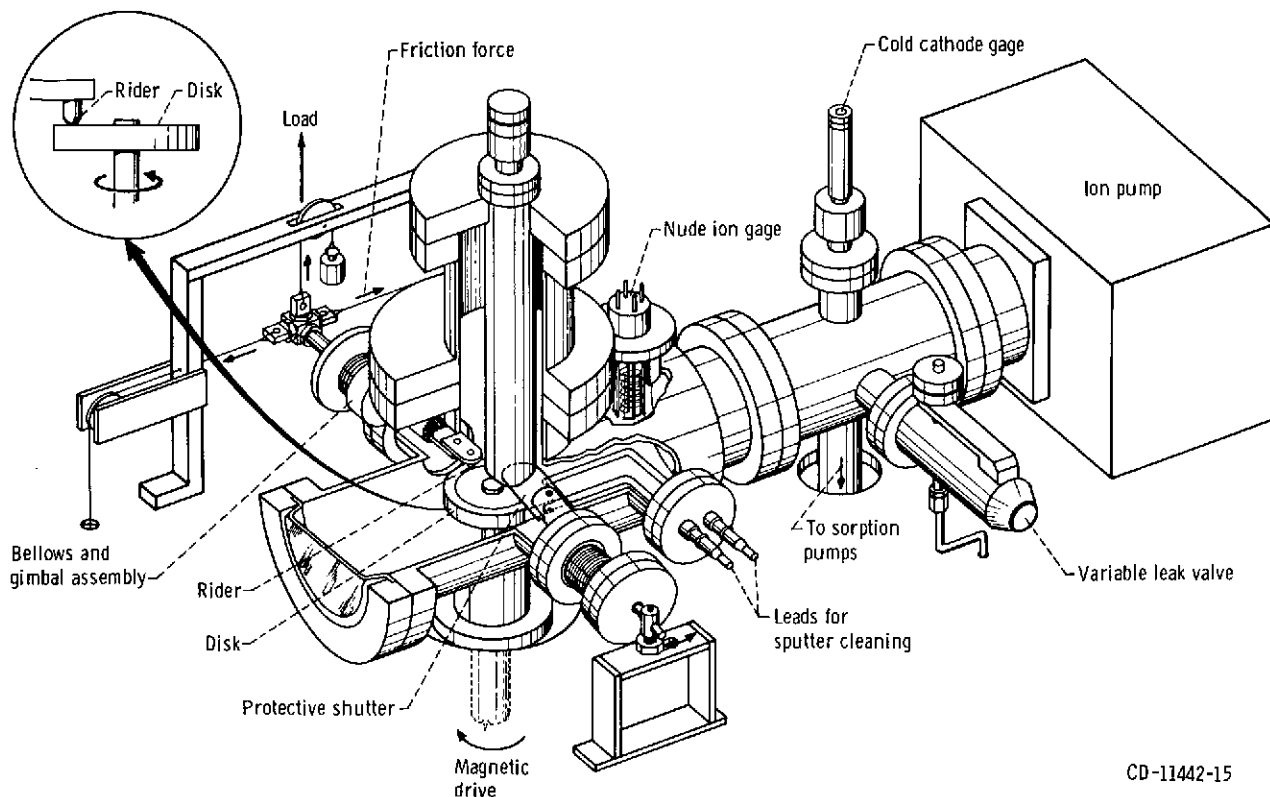


Figure 1. - Friction apparatus with Auger spectrometer.

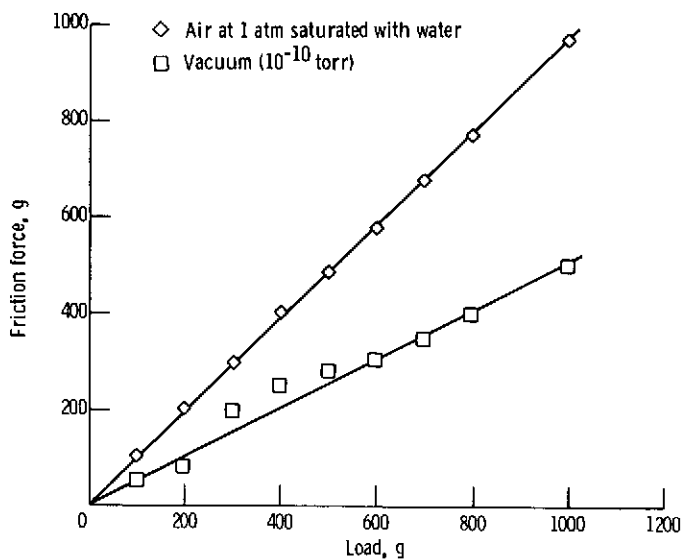


Figure 2. - Friction force as function of load for glass sliding on glass. Sliding velocity, 30 centimeters per minute; temperature, 23° C.

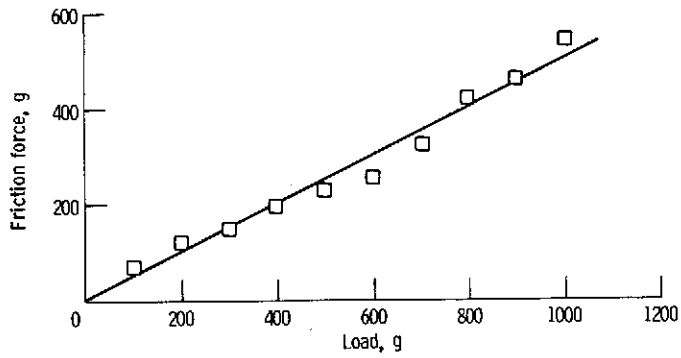


Figure 3. - Friction force as function of load for aluminum sliding on glass. Vacuum; sliding velocity, 30 centimeters per minute; temperature, 23° C.

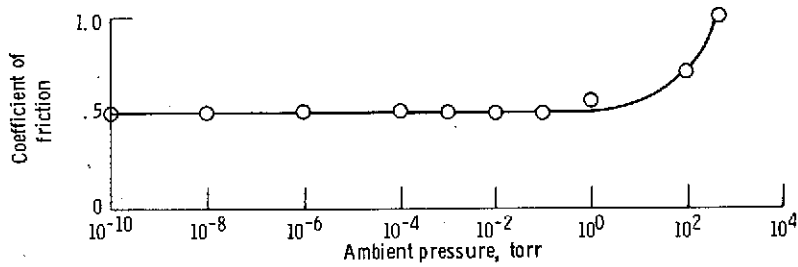


Figure 4. - Friction coefficient for glass sliding on glass as function of ambient pressure. Moist air; sliding velocity, 30 centimeters per minute; load, 100 grams; temperature, 23° C.

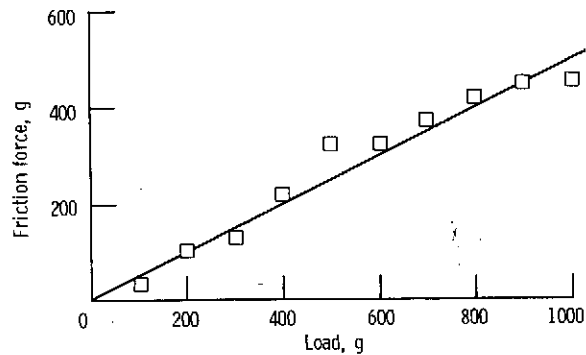


Figure 5. - Friction force as function of load for iron sliding on glass. Vacuum sliding velocity, 30 centimeters per minute; temperature 23° C.

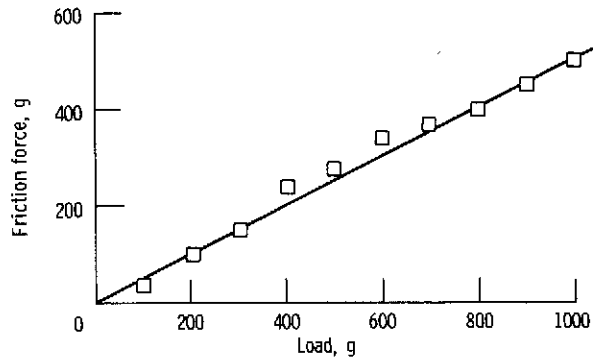


Figure 6. - Friction force as function of load for gold sliding on glass. Vacuum; sliding velocity, 30 centimeters per minute; temperature 23° C.

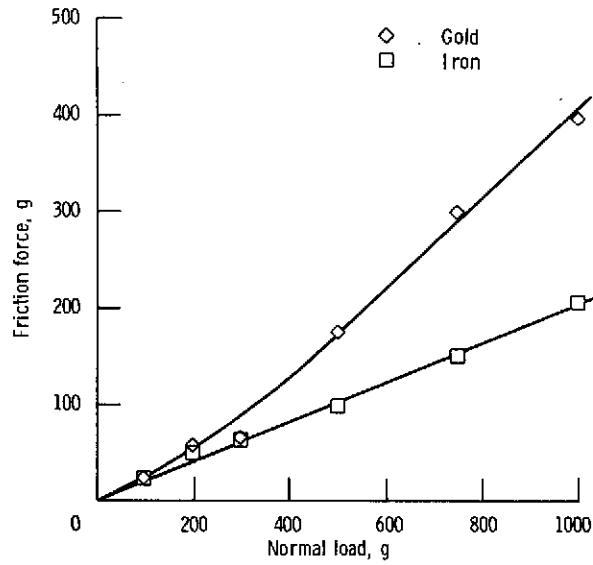


Figure 7. - Friction force at various normal loads for gold and iron sliding on glass lubrication with thin film of octane. Moist air; sliding velocity, 30 centimeters per minute; temperature, 23° C.

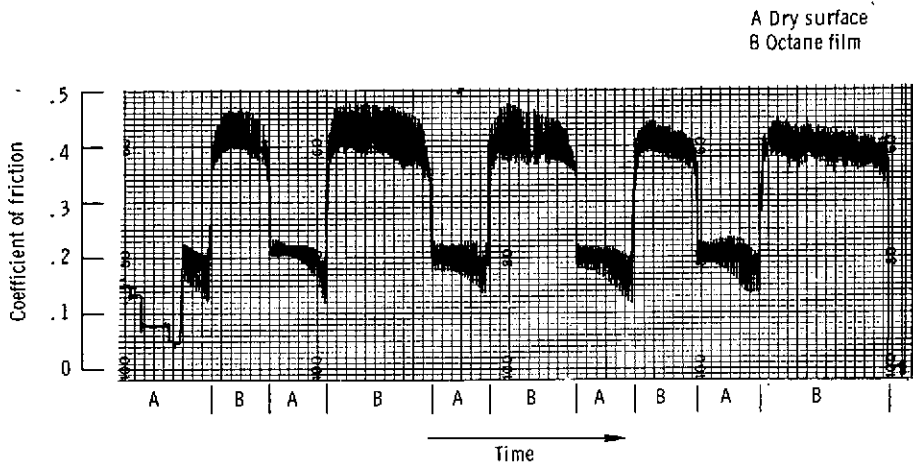


Figure 8. - Coefficient of friction for gold sliding on glass with and without octane film. Moist air; sliding velocity, 30 centimeters per minute; load, 100 grams; temperature, 23° C.

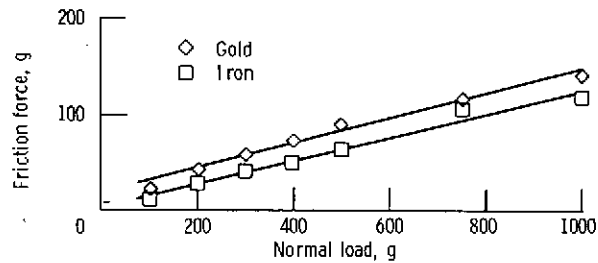


Figure 9. - Friction force as function of normal load for gold and iron sliding on glass lubricated with 0.20 percent stearic acid in hexadecane. Sliding velocity, 30 centimeters per minute; temperature, 23° C.

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