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TEXTURING IN METALS AS A RESULT OF SLIDING

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16. Abstract

Sliding friction experiments were conducted with copper, nickel, iron, and cobalt sliding on themselves in air and argon. The resulting wear surfaces were examined with X-ray analysis to determine if surface texturing had occurred as a result of sliding. Results of the investigation indicate that, for the face-centered-cubic metals copper and nickel, a (111) texture develops with the (111) planes tilted 10° in the direction of sliding. The body-centered-cubic metal iron exhibited a (110) texture with the [111] direction oriented in the direction of sliding. It also exhibited a 10° tilt in the direction of sliding. The environment influenced the results in that the degree of texture observed in argon was less than that seen in air for iron. No texturing was observed for the close-packed-hexagonal metal cobalt. Recrystallization was observed with copper as a result of sliding.

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SUMMARY

Sliding friction experiments were conducted with copper, nickel, iron, and cobalt sliding on themselves. Sliding studies were performed both in air and argon. Surfaces were examined in the wear region after sliding with X-ray analysis to determine if texturing had occurred. Texturing was determined after a varied number of passes of a hemispherical rider over a flat disk surface. The effect of load on texturing was also examined.

The results of this investigation indicate that, for face-centered-cubic metals such as copper and nickel, a (111) surface texture develops as a result of sliding with the (111) planes tilted 10° in the direction of sliding. With body-centered-cubic metals such as iron, a (110) surface texture develops with the [111] crystallographic direction oriented in the direction of sliding. There was also a 10° tilt in the direction of sliding. Under the conditions of this study, texturing was not observed in cobalt. The environment influenced the texturing results for iron but not for copper. In argon, the degree of texturing was not as great as was observed in air for iron. Surface recrystallization was observed for copper as a result of sliding.

INTRODUCTION

The mechanical processing of metal surfaces results most frequently in the development of texturing (preferred orientation of grains) in the surficial layer (depth of material affected). The preferred orientations or surface textures that develop depend heavily on the method of mechanical finishing. For example, with a particular metal or alloy, rolling may give a different texture than forging. Even if a surface does not exhibit texturing on components prior to their use in lubrication systems, the sliding, rubbing, or rolling process involved in these systems may give rise to the development of surface textures.

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A limited amount of research has been conducted to determine the influence of texturing on friction and wear and the role played in the dynamic contact of lubrication system components in the development of textures. Wilman and coworkers have examined the development of textures during abrasion (refs. 1 and 2). More recently, the texturing of cobalt and cobalt alloys has been examined during the rubbing process (ref. 3). A systematic study is, however, still lacking.

The objective of this investigation was to determine the influence of sliding on the development of surface textures in metals. Three metals were selected for study as representatives of each of the major crystal systems in which alloys used in lubrication systems are generally found. Iron was selected as representative of body-centered-cubic metal behavior, copper and nickel as representative of the face-centered-cubic system, and cobalt as the close-packed-hexagonal representative. Friction experiments in dry sliding were conducted with each of the metals sliding on itself. Wear surfaces were then examined with an X-ray analysis to determine the degree and type of texturing.

MATERIALS

The copper disk and rider specimens used in this study were 99.998 percent copper. The iron specimens were prepared from 99.95 percent iron. Cobalt disks and riders were prepared from 99.9+ percent cobalt. The nickel was 99.99 percent in purity.

The disk specimens were prepared by lapping, diamond polishing, and finishing with 0.3-micron alumina. The riders were given a 0.475-centimeter radius and then finished with 240, 320, 400, and 600 grit metallurgical papers. They were finally polished with 3.0-micron alumina.

APPARATUS

Friction and Wear Device

The apparatus used to conduct friction and wear experiments is shown schematically in figure 1. The basic components of the apparatus are a 6.25-centimeter-diameter disk specimen 1.27 centimeters thick and a rider specimen with a 0.5-centimeter radius. The disk specimen is rotated by a variable speed electric motor. Speed can be varied from 300 to 5250 centimeters per minute. The rider specimen is contained in an arm which has incorporated in it a strain-gage assembly for recording friction force. The rider is deadweight loaded against the disk. The disk and rider were of the same materials in each experiment.

The apparatus is covered with a clear plastic box in which a positive argon pressure can be maintained. While the argon purge was not intended to exclude oxygen and water vapor totally, it was intended to minimize the concentration of these gases and to maintain a relatively constant environment from experiment to experiment.

X-Ray Instrument

The X-ray instrument was a General Electric XRD-5 with a chromium targeted tube. Radiation was filtered with a vanadium oxide film.

Samples (disk specimens) were mounted in a special jig on a standard goniometer base in an orienter goniostat. The sample could be manually rotated about its own axis while counts were taken so that the intensities are averages over a number of equally spaced points around the disk.

A pin hole collimator was used because the wear track was normally only a few millimeters wide. The medium resolution (MR) soller slits were used at the detector, but no vertical slit was used; the entire filter mounting fixture was removed to give the widest possible angle of acceptance at the detector. This is in accord with the suggestions of Chernock and Beck (ref. 4).

The schematic arrangement of the X-ray beam relative to the disk is shown in figure 2. The primary beam (source) is directed into the wear track. The reflected beam is collected with a counter. The wear track can be tilted in two directions (φ and β) as indicated in figure 2. The texture of the wear surface can be determined by rotating in the φ- and β-directions.

With the sample properly alined, a randomly oriented, lapped copper disk specimen gave a (111) intensity that decreased by less than 10 percent as the disk was tilted 60° from the normal (vertical) position. This was done to show that the specimens prior to sliding were truly randomly oriented.

RESULTS AND DISCUSSION

Copper

Sliding friction experiments were conducted in argon with copper sliding on copper at three different loads of the rider against the disk. The sliding velocity was 5.18 centimeters per second, and sliding was continued until the rider had achieved 1000 passes against the disk surface. The resulting wear tracks generated on the copper disk surface were then examined with X-ray analysis. The (111) plane intensity is plotted as a function of polar angle (its position relative to the sliding direction) in figure 3.

An examination of figure 3 indicates that the maximum (111) intensity is achieved when the polar angle φ is nearly normal. This then indicates that, as a result of sliding, texturing of the initially random oriented surface layers has occurred. Figure 3 in combination with the pole figure (polar plot) of figure 4 establishes that the (111) planes or preferred slip planes in the face-centered-cubic metal copper are oriented nearly parallel (within 10°) to the sliding direction with the tilt in the planes in the direction of sliding. The elongation of the contours perpendicular to the sliding direction results from scoring of the wear track. This condition is a consequence of curvature across the width of the wear trace. Such curvature produces a rotation of the (111) about an axis parallel to the sliding direction.

In figure 4 the small circle in the upper half of the pole figure indicates maximum (111) intensities. The fact that the small circle is not in the center of the pole figure indicates that the (111) orientation is tilted out of normal to the sliding direction. Its position in the upper half of the pole figure is 10°. The dashed line indicates the area scanned.

The data of figure 3 obtained at three different loads indicate that the kind and degree of texturing is the same at all three loads investigated. The data points for all three load conditions can be plotted on a single curve. A curve obtained in an experiment conducted at a 50-gram load showed significantly less texture, but the wear track was very narrow indicating that the X-ray beam may have sampled regions on either side of the wear track and this could have affected the results.

The (111) planes in copper, being the highest atomic density planes, have the lowest surface energy. Also, since the distance between these planes is great, easy slip and shear result. It would, therefore, be anticipated that the orientation of these planes near parallel to the sliding direction would result in a minimum in friction. Friction experiments substantiate that this is, in fact, the case (refs. 5 and 6).

In order to determine if surface films (oxides and adsorbed layers) exert an influence on the texturing behavior of copper, sliding experiments were conducted in air. The results of these experiments were compared to those obtained in argon. The effect of repeated passes over the same surface on the texturing of copper in argon is demonstrated by the data of figure 5. At repeated passes to 2400, there appears to be very little influence of the number of passes on texturing. At 6000 passes, a slight decrease in the degree of surface texture appears to have occurred. This slight decrease may be due to surface recrystallization resulting from frictional heating. After sliding the grain size was reduced, thus giving other evidence for recrystallization.

The data point obtained in air at 1000 passes coincides with one obtained in argon, which indicates that the absence of oxygen to replenish worn away surface oxides does not affect the texturing of copper. This result may be due to the relatively weak nature of the copper oxide.

The decrease in the amount of surface texture after 6000 passes in figure 5 indicated that recrystallization may have been occurring during sliding. To determine if in fact recrystallization were occurring, some copper disk specimens were annealed after sliding. After 400 passes, a copper disk was annealed at 400° C for $1\frac{1}{2}$ hours. The (111) peak intensities before and after annealing as a function of polar angle are presented in figure 6.

Annealing at 400° C is sufficient to allow for recrystallization of copper (ref. 7). Thus, even after recrystallization, there remains a (111) surface texture. The intensity (degree) has simply decreased. These data would then lend weight to the argument that in figure 5 the decrease in the amount of texture observed after 6000 passes was due to recrystallization.

An examination of figure 6 indicates that the before annealing curve is very near to that obtained in figure 3 after 1000 passes. It is evident from figure 6 that the same degree of texture can be achieved in only 400 passes. The important point to be made from figure 6 is that after annealing the maximum is reduced relative to its minima, which indicates that annealing has reduced the amount of surface texture.

Further evidence for the recrystallization argument after 6000 passes is obtained from the data of figure 7. In figure 7 the (111) intensity is plotted as a function of polar angle after 6000 passes both before and after annealing. A heavy oxide layer was observed on one disk surface after annealing. This may account for the overall intensity decrease of both figures 6 and 7. With annealing the entire curve is shifted downward. The relative position of the maxima to minima has remained, however, essentially unchanged. Thus, except for an overall decrease in intensity, the two curves of figure 7 are essentially the same. The results indicate that sliding to 6000 repeated passes produces the same result as recrystallization. In both cases there was a change in grain size.

Nickel

In order to determine if other face-centered-cubic metals behave like copper with respect to texturing, a sliding friction experiment was conducted with nickel sliding on itself. These experiments were conducted to see if the same general type of surface texture develops for face-centered-cubic metals in general. The wear surface after 1000 passes was examined with X-ray analysis to determine the surface texture developed. The pole figure resulting from such an analysis is presented in figure 8.

The pole figure of figure 8 indicates that nickel behaves in a manner similar to that observed for copper. The {111} planes are nearly parallel (within 10°) to the sliding direction. The same texture develops for these two face-centered-cubic metals despite marked differences in mechanical properties.

Iron

The alloys which receive the most use in practical lubrication systems are body centered cubic and are principally iron in composition. Therefore, a rather detailed analysis of iron textures was conducted. Sliding friction experiments were therefore conducted with iron sliding against iron. An examination of the wear surface with an X-ray analysis after 1200 passes at a 500-gram load produced the pole figure of figure 9.

In three repeated experiments the (110) plane is almost parallel to the direction of sliding. It is, however, tilted about 10° in the direction the rider was sliding (indicated by the arrow of fig. 9). This 10° tilt behavior is analogous to the tilt behavior seen in the face-centered-cubic metals copper and nickel.

The area of the sterographic projection that could be examined is within the dashed contour of figure 9. The elongation of the contours perpendicular to the sliding direction, as with copper, is due to curvature across the width of the wear track.

With iron, not only the preferred plane but the slip direction can be identified. The triangular symbols of figure 9 indicate where peaks would occur if the sample were a single crystal with its (110) face parallel to the surface and its [111] direction in the sliding direction. Except for the 10° tilt in the direction of sliding, the wear surface has this texture.

Experimental results with copper indicated that environment exerted essentially no influence on texture results. Similar environmental determinations were made for iron. Friction experimental results obtained in an argon environment are compared with experimental results obtained in air in figure 10.

Figure 10 is a plot of the (110) texture peak intensities as a function of the number of passes. In air the degree of texturing developed with sliding is greater than was observed in argon. The reduction of oxygen and water vapor results in less texturing in all probability because of a lack of replenishment of residual surface oxide. As the residual surface oxide is worn away in argon, it is not replaced and the amount of adhesion and adhesive transfer increases. With adhesive transfer, large particles are removed from the disk surface. Subsurface fracture must occur to give rise to the generation of these particles. Thus, if orientation subsurface is random, this random orientation will be exposed to the X-ray beam decreasing the total amount of texture observed. The net effect is a decrease in peak intensity.

It would appear that the aforementioned hypothesis is supported by the data of figure 10. In figure 10, the texture (110) peak intensity decreases with an increase in the number of passes in argon. In air this decrease is not observed.

This position is further substantiated by the surface profile traces of figure 11. In figure 11, iron wear trace profiles obtained in air are compared with those obtained in argon. After 300 passes in both air and argon, the argon track is wider indicating greater wear to the rider specimen. When 3100 passes in air had been completed and only 3000 passes in argon, the argon track showed considerable evidence for material removal. Examination of figure 10 indicates that at this point there is also evidence for a decrease in the amount of texturing observed.

Cobalt

The authors of reference 2 have observed the development of the basal texture (0001) on the surface of cobalt in sliding friction studies. This is the texture which might be anticipated. In the present investigation, texturing was not observed in cobalt in repeated sliding experiments. It must be indicated that the loads employed in this study were considerably less than those obtained by the authors of reference 2. Since there are notably fewer slip systems in the hexagonal metals such as cobalt than in the cubic metals, texturing could be expected to be very sensitive to load.

CONCLUSIONS

Based on the experimental results obtained in this investigation with X-ray texture analysis of copper, nickel, iron, and cobalt wear surfaces, the following conclusions are drawn:

1. Texturing of face-centered-cubic metals, such as copper and nickel, and body-centered-cubic metals, such as iron, occurs very readily during sliding contact of these metals.

2. With face-centered-cubic metals (copper and nickel), the preferred crystallographic (111) slip plane orients itself within 10° of the sliding direction. Tilt of the plane is in the sliding direction. Varying the load on copper from 150 to 500 grams had no effect on texturing.

3. The body-centered-cubic metal iron textures with the (110) crystallographic slip plane oriented within 10° of the sliding direction. Furthermore, the [111] crystallographic direction is oriented in the direction of sliding.

4. Environment plays a role in the degree of surface texture observed for some metals. With iron the degree of texturing observed in argon was less than that occurring in air. With copper, however, no environmental effect was observed.

5. At the light loading levels used in this study texturing was not observed in the close-packed-hexagonal metal cobalt. It appears, however, that texturing in cobalt is more difficult to observe because of the limited number of operable slip systems.

6. With copper sliding under the mechanical conditions of load and speed employed in this investigation, surface recrystallization was observed to occur in sliding.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, October 25, 1972,
502-01.

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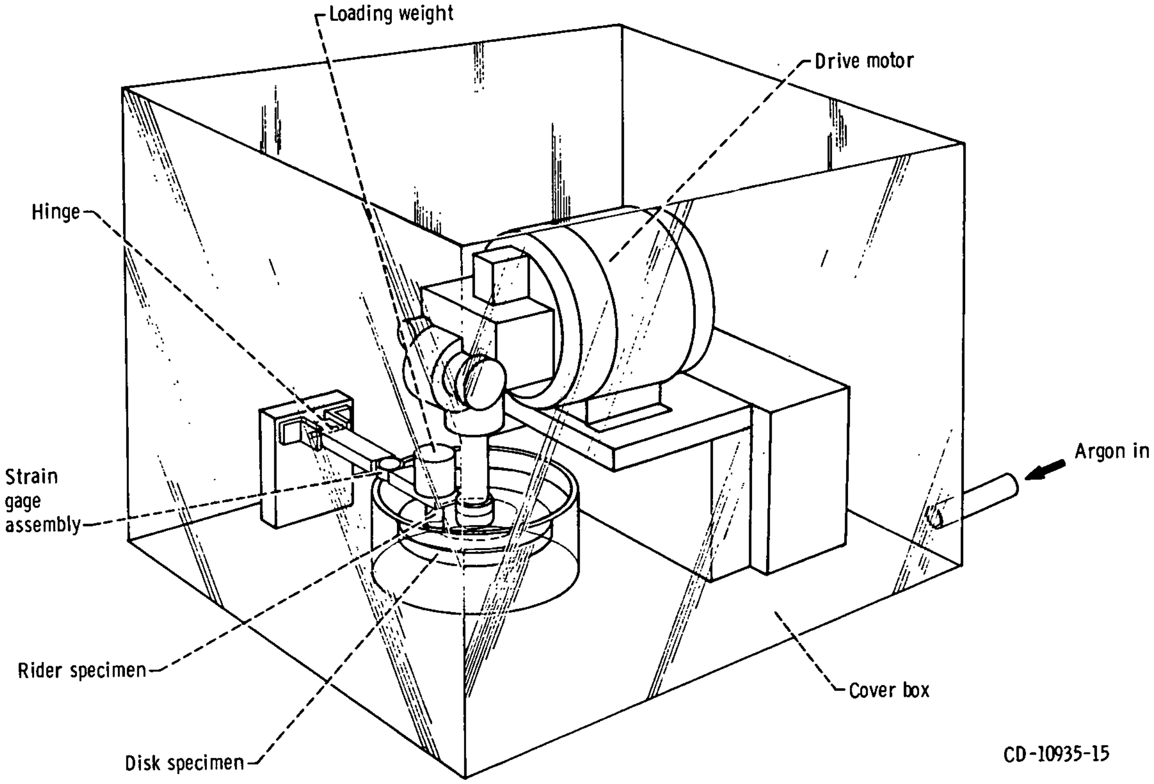

Figure 1. - Friction apparatus.

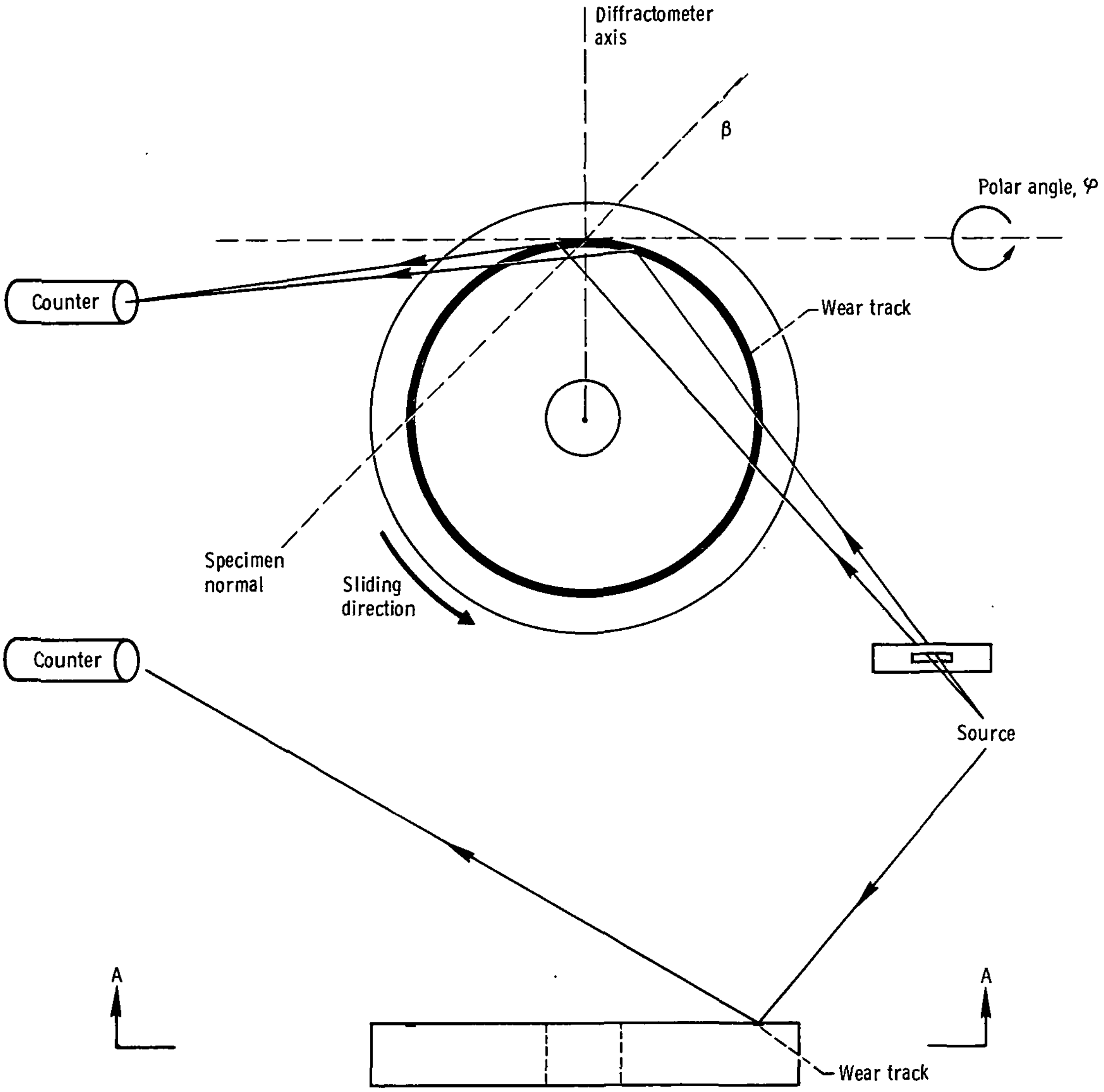

Figure 2. - X-ray examination of disk specimen after sliding.

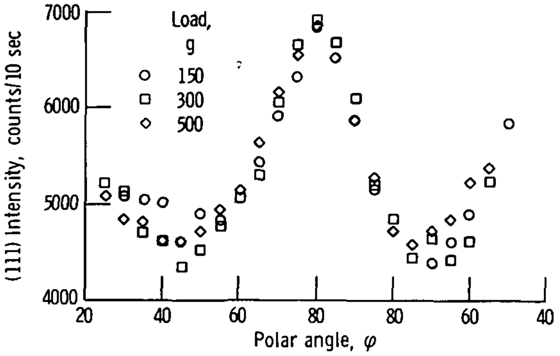

Figure 3. - X-ray analysis of copper wear track (111) intensity plotted as function of polar angle φ. Copper sliding on copper in argon at three loads; total of 1000 passes at sliding speed of 5.18 centimeters per second and ambient temperature of 23^0 C; specimen rotated relative to sliding direction.

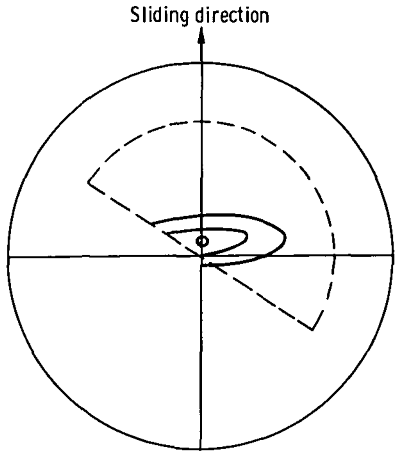

Figure 4. - X-ray (111) pole figure for surface texture developed on copper disk surface as result of sliding. Sliding continued for total of 1000 passes at sliding velocity of 5.18 centimeters per second; load, 300 grams; ambient temperature, 23^0 C. Solid lines represent texture and dashed lines represent boundary projected area.

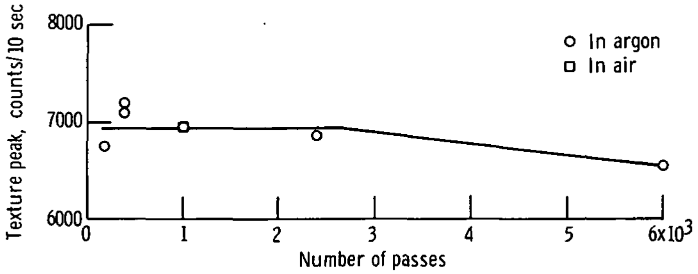

Figure 5. - Texture peak intensity in copper wear track as function of number of passes across surface in both air and argon. Sliding velocity, 5.18 centimeters per second; load, 300 grams; ambient temperature, 23^0 C.

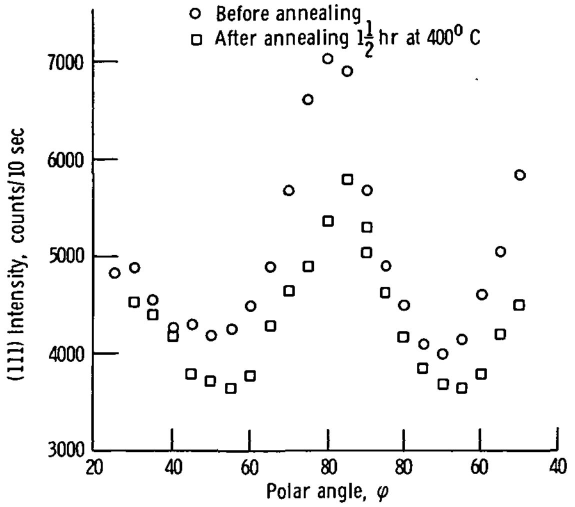

Figure 6. - Copper (111) X-ray peak intensities as function of polar angle for copper disk prior to and after annealing a 400 pass wear track. Sliding velocity, 5.18 centimeters per second; load, 300 grams; ambient temperature, 23° C.

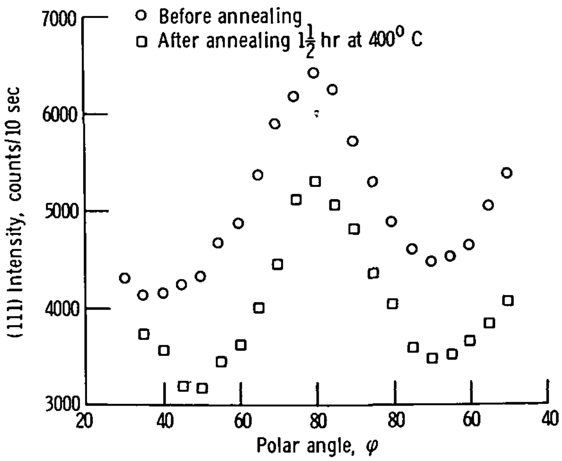

Figure 7. - (111) Copper peak intensities plotted as function of polar angle φ for copper wear surface after 6000 passes and before and after annealing. Sliding velocity, 5.18 centimeters per second; load, 500 grams; in argon at 23° C.

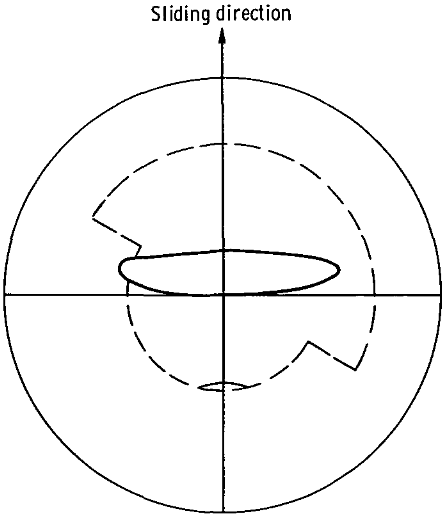

Figure 8. - X-ray pole figure (111) for wear track on nickel surface after 1000 passes. Sliding velocity, 5.18 centimeters per second; load, 500 grams; in argon at 23° C.

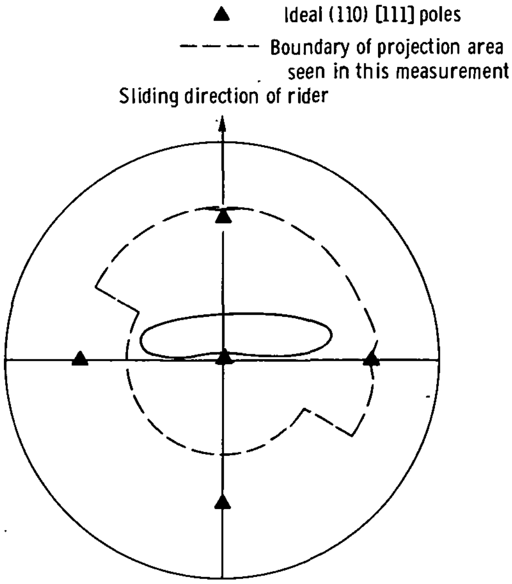

Figure 9. - X-ray (110) pole figure for iron wear track after 1200 passes of iron rider over iron disk surface. Sliding velocity, 5.18 centimeters per second; load, 500 grams; in air at 23° C.

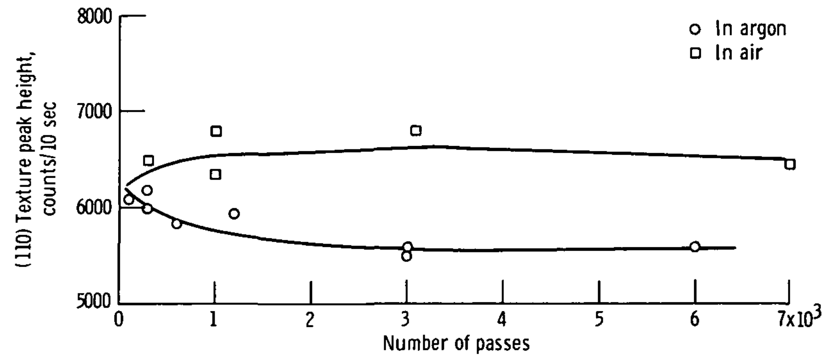

Figure 10. - X-ray (110) texture peak height plotted as function of number of passes of rider across disk in both air and argon. Sliding velocity, 5.18 centimeters per second; load, 500 grams; temperature, 23° C.

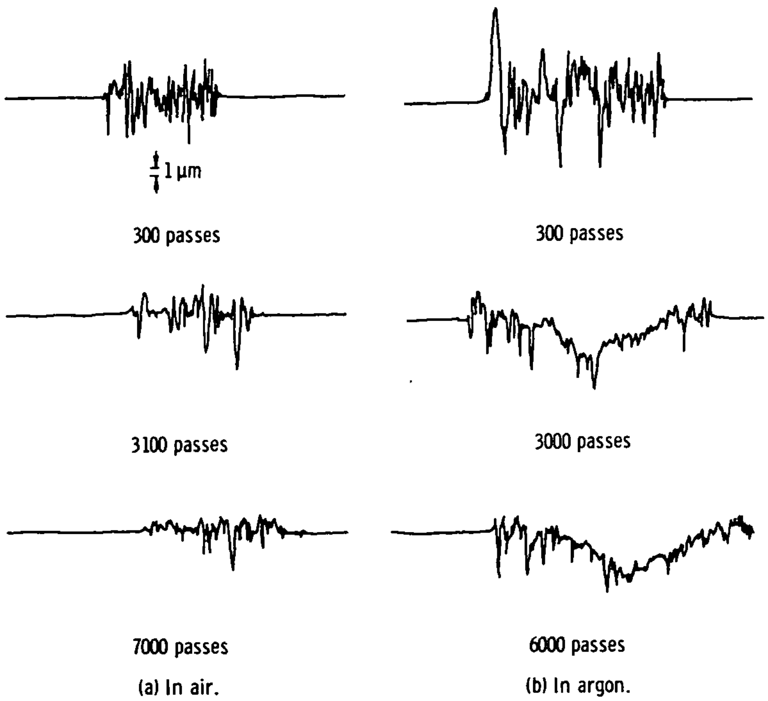

Figure 11. - Iron wear track profiles. Sliding velocity, 5.18 centimeters per second; load, 500 grams; temperature, 73° C.

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