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Friction and Morphology of Magnetic Tapes in Sliding Contact With Nickel-Zinc Ferrite

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Summary

An investigation was conducted to examine the friction and deformation behavior of magnetic tapes in contact with a Ni–Zn ferrite hemispherical pin in air. The effect of binder composition on coefficient of friction was also examined. Friction experiments were conducted with loads up to 1.0 N at a sliding velocity of 1.5 mm/min with single-pass sliding in laboratory air at a relative humidity of 40 percent and at room temperature. Multipass sliding experiments were also conducted in reciprocating motion.

The friction behavior of the tape can be divided into two categories based on the nature of surface deformation. In elastic contacts the friction decreased as the load increased. In plastic contacts the friction increased as the load increased. The coefficient of friction in elastic contacts was considerably lower than it was in plastic contacts. The composition of the binder was an important factor controlling the friction properties, morphology, and microstructure of the tape. Comparison was made with four binders: nitrocellulose; poly (vinyledene) chloride; cellulose acetate; and hydroxyl-terminated, low-molecular-weight polyester added to polyester-polyurethane. The coefficient of friction was lowest for the tape with the nitrocellulose binder and increased in the order hydroxyl-terminated, low-molecular-weight polyester resin; poly (vinyledene) chloride; and cellulose acetate. The degree of enclosure of the oxide particles by the binder was highest for hydroxyl-terminated, low-molecular-weight polyester and decreased in the order cellulose acetate, poly (vinyledene) chloride, and nitrocellulose.

Introduction

Magnetic recording has been developed to a highly refined state. The term can be applied to any recording technique in which some phase of magnetics is intimately associated with either the recording or playback process. In most magnetic recording and playback devices, recording is done on a magnetic medium, such as a magnetic tape or disk.

The most common medium is tape, in which a suspension of magnetic powder in a binder is coated on a flexible backing (substrate) used for strength. The common oxide powder materials are γ-Fe_2O_3 and CrO_2 in small particles 1 μm or less in size. The particles, which are needlelike in shape, are oriented by a magnetic field during the coating process. Magnetic tapes normally use γ-Fe_2O_3 or CrO_2 powder held in a polymeric binder. Some common polymeric binders are polyester-polyurethane, cellulose acetate, cellulose nitrate, epoxy resins, and vinyl compounds. Acetate and polyester films are commonly used as the backing. The polyester backing has the advantage of being dimensionally quite stable with temperature or humidity.

A small amount of magnetic head and medium wear may render the recording process unreliable. The gradual change accompanying the wear process in characteristics of the head and medium has been the concern of manufacturers of tapes, heads, and recording devices.

The magnetic tape is, alone, a major contributor to differences in characteristics of recording devices and head life. Manufacturing variations, which determine the smoothness of the coating and the degree of enclosure of the oxide particles by the binder, are obvious factors controlling the tribological properties of tapes.

Much of the research conducted with tapes and heads in the magnetic recording industry was and is empirical (refs. 1 to 7). Investigators have concerned themselves with such factors as contact pressure, relative sliding velocity, temperature, hardness, and humidity and have used onsite testing or other short-cut methods. The question is, Have we really learned anything that assists us in understanding the fundamental mechanisms involved with such tribological characteristics as friction and wear of the tape and head and thus in achieving low friction and high wear resistance? The answer is that we have learned very little.

Miyoshi and Buckley commenced fundamental studies on the friction and wear behavior of Mn–Zn and Ni–Zn ferrites in order to gain an understanding of the tribological properties of ferrites (refs. 8 to 12). The results indicated that the coefficients of friction for ferrites in contact with various metals are related to the relative chemical activity of the metals: the more active the metal, the higher the coefficient of friction (refs. 9 and 10). They also correlated the coefficient of friction with the free energy of formation of the lowest metal oxide. The interfacial bond can be regarded as a chemical bond between the metal atoms and the oxygen anions in the ferrite surface. It was found that mating the highest atomic density directions and planes of ferrite surfaces resulted in the lowest friction; this suggested that crystallographic orientation is important in the friction behavior of ferrites (ref. 11). Fracture wear of ferrites as a result of sliding was determined to be due to primary cleavage of the (110) planes (ref. 11). The present study extends this investigation to tribological properties of magnetic tapes in contact with ferrites.

This study was conducted to examine the friction and deformation behavior of magnetic tapes in contact with a Ni–Zn ferrite hemispherical pin. The effect of binder on the coefficient of friction was also examined. All experiments were conducted with loads to 1.0 N, at a sliding velocity of 1.5 mm/min with a total sliding distance of 10 mm in single-pass sliding, in laboratory air at a relative humidity of 40 percent, and at room temperature. Multipass sliding experiments were also conducted in reciprocating motion.

Materials

The magnetic tapes used in this investigation contained γ-Fe_2O_3, CrO_2, and cobalt-modified (doped) γ-Fe_2O_3 powders coated on a polyester film backing (film thickness, 23 μm; and film width, 12.7 mm). The powder, binder, and lubricant of the tape are shown in table I. Table I also presents data on surface roughness and Knoop hardness.

The hot-pressed polycrystalline Ni-Zn ferrite (66.6 wt% Fe_2O_3; 11.1 wt% NiO; and 22.2 wt% ZnO) is a ceramic semiconductor. The grain size of the Ni-Zn ferrite was about 8 μm (ref. 12), and its porosity was less than 0.1 percent.

Apparatus and Experimental Procedure

The apparatus used in this investigation is shown in figure 1. It was basically a pin (rider) on a flat. The magnetic tapes were mounted on hardened steel flats and retained in a vice mounted on a screw-driven platform. The platform was driven through the screw by an electric motor with a gearbox that allowed for changing the sliding velocity. Motion was reciprocal. The pin was made to traverse a distance of 10 mm on the surface of the tape. A switch then reversed the direction of motion so that the pin retraced the original track from the opposite direction. This process was continuously repeated.

The Ni-Zn ferrite hemispherical pin specimen was loaded against the magnetic tape with deadweights. The arm retaining the pin contained strain gages to measure the tangential force. The arm could be moved normal to the direction of the wear tracks and thus multiple tracks could be generated on a single surface. The entire apparatus was housed in a plastic box.

The pin was polished with a diamond powder (particle diameter, 3 μm) and with an aluminum oxide (Al_2O_3) powder (1 μm). The radius of the pin was 2 mm. The pin surface was rinsed with 200-proof ethyl alcohol. The Ni-Zn ferrite pin and magnetic tape specimen were placed into the experimental apparatus. The specimen surfaces were then brought into contact and loaded.

To obtain consistent experimental conditions, contact was maintained for 30 s before sliding, and then the friction experiment was begun. Both the load and the friction force were continuously monitored during a friction experiment. Sliding velocity was 1.5 mm/min over a total sliding distance of 10 mm.

TABLE I. – COMPOSITION AND PROPERTIES OF MAGNETIC TAPES

Tape	Magnetic particle	Binder	Lubricant	Surface roughness,[a] nm	Knoop hardness at 13° C,[b] MPa
1	CrO_2	Polyester-polyurethane and phenoxy	Butyl stearate and butyl palmitate	14.4	225
2	γ-Fe_2O_3	Polyester-polyurethane and epoxy	Butyl myristate	8.5	157
3	Cobalt-doped γ-Fe_2O_3	Polyvinyl chloride, polyvinyl acetate, polyvinyl alcohol, poly (vinyledene) chloride, and polycarbonate	Butyl stearate and butyl palmitate	15.1	490
4	Cobalt-doped γ-Fe_2O_3	Polyester-polyurethane, polyvinyl chloride, and polyvinyl acetate	Butyl ethyl stearate	13.6	118
5	CrO_2	Nitrocellulose and polyester-polyurethane	Fatty acid esters	27.3	178
6	↓	Poly (vinyledene) chloride and polyester-polyurethane	↓	27.2	(c)
7	↓	Cellulose acetate and polyester-polyurethane	↓	20.0	(c)
8	↓	Hydroxyl-terminated, low-molecular-weight polyester resin and polyester-polyurethane	↓	26.5	(c)

[a]Root-mean-square roughness.
[b]Measuring load of hardness, 0.0013 N.
[c]Not measured.

Results and Discussion

Friction and Deformation

Single-pass and multipass sliding friction experiments were conducted with a magnetic tape containing CrO_2 particles in a binder of polyester-polyurethane and phenoxy (tape 1 in table I) in contact with a polycrystalline Ni–Zn ferrite pin in laboratory air. Figure 2 presents a trace of coefficient of friction as a function of sliding time. The trace is relatively smooth, with no evidence of stick-slip.

The coefficients of friction measured at various loads on the tape are presented in figure 3(a). The coefficient of friction was not constant but decreased as the load increased at loads up to 0.25 N. On the other hand, above 0.25 N the coefficient of friction increased as the load increased. Figure 3(b) presents data for the coefficients of friction as a function of the number of passes. When repeated passes were made, the coefficient of friction for the tape exhibited generally small changes with the number of passes at any load up to 1.0 N. The data of figure 3 raise the question of how the interface deforms with sliding action.

The tracks on the tape, which the ferrite pin was made to traverse, were different with different loads to 1.0 N when examined by optical and scanning electron microscopes. Essentially no detectable wear track existed on the surface of the tape at a load of 0.1 N. The surface of the track was very similar to that shown in figure 4(a). Figure 4(a) presents an example of the surface of the as-received magnetic tape (tape 1). At 0.25 N and above, the sliding action produced a visible wear track on the magnetic tape, as typically shown in figure 4(b). The scanning electron micrograph clearly reveals a degree of plastic deformation at the tips of the asperities on the magnetic tape. Thus although the sliding ocurred at the interface, elastic deformation occurred in both the tape and the Ni–Zn ferrite at loads to 0.25 N. At 0.25 N and above, plastic deformation occurred in the tape, but the Ni–Zn ferrite primarily deformed elastically. Figure 4(b) shows the blunt appearance of the asperities on the wear track after 5 sliding passes. This bluntness resulted primarily from the plastic deformation of asperities on the tape.

From the nature of deformation at the interface between the hemispherical pin and the flat, friction behavior can be generally divided into two categories, as indicated in figure 5. In the elastic contact region the friction decreased as the load increased. The relation between coefficient of friction μ and load W is given by an expression of the form $\mu = KW^{-1/3}$ (ref. 13). The minus 1/3 power can be interpreted simply as arising from an adhesion mechanism, with the area of contact being determined by elastic deformation as was observed herein.

For example, figure 6 presents the coefficient of friction measured for the polyester backing in contact with the Ni–Zn ferrite pins at various loads. The data of figure 6 indicate that the coefficient of friction decreased as the load increased. With sliding, elastic deformation occurs in the surfaces of both the polyester backing and the Ni–Zn ferrite pin (refs. 13 and 14).

By contrast, when deformation was plastic, the coefficient of friction for a hard, spherical solid pin in contact with a soft solid tape increased as the load increased, as indicated in figure 5(b). A typical example of this is presented in figure 3(a).

To aid our understanding of how manufacturing variations of tapes, which determine smoothness of coating and degree of enclosure of the oxide particles by the binder, are important to tribological properties, experiments were conducted with tapes 2 to 4.

Figure 7 presents scanning electron micrographs of the as-received surface of a tape containing γ–Fe_2O_3 particles in a binder of polyester-polyurethane and epoxy (tape 2 in table I) and of a typical wear track on the tape. The surfaces shown in figure 7 are topographically oriented, and the oxide particles were also oriented by a magnetic field during the coating process. The surface profiles are quite different from those presented in figure 4 (tape 1). Figure 7(b) illustrates, however, that plastic flow occurred on the tape with repeated sliding. The sliding direction is indicated by the arrow in figure 7(b).

Figure 8 presents the coefficient of friction for tape 2 as a function of load and number of repeated passes. The friction behavior as a function of load was similar to that of tape 1 (fig. 3(a)). When repeated passes were made, the coefficient of friction for the tape decreased as the number of passes increased. Thus the surface finish was an obvious factor controlling the topography and friction behavior of the tape.

Further sliding friction experiments were conducted with tapes 3 and 4 (table I). Two material variations with these tapes are lubricant and binder. Figure 9 presents the coefficients of friction for tapes 3 and 4 as a function of load and the number of repeated passes. The tapes contain cobalt-doped γ–Fe_2O_3 (table I). The coefficients of friction for tape 3 are markedly different from those for tape 4. Plastic deformation occurred with tape 3 over the entire load range from 0.1 to 1.0 N. When repeated passes were made, the coefficient of friction for tape 3 decreased as the number of passes increased. This behavior may also relate to the plastic deformation of tape 3. The coefficients of friction for tape 4 were generally the same as those obtained with tape 1.

Figures 10 and 11 present scanning electron micrographs of the as-received surfaces of tapes 3 and 4 and of the wear tracks on those tapes. The as-received surface of tape 3 had a coarser structure than that of tape 4, but considerable plastic flow occurred in both tapes 3 and 4. It is obvious that lubricant and binder are factors controlling the frictional properties of the tape and their morphology as well as their microstructure.

Effect of Binder on Friction

To determine the effect of binder on frictional properties, sliding friction experiments were conducted with four tapes: tapes 5 to 8 in table I. The tapes were controlled with respect to all variables in material properties except the binder. The lubricant was a fatty acid ester. In addition to polyester-polyurethane, the binders of tapes 5 to 8 contained nitrocellulose, poly (vinyledene) chloride, cellulose acetate, and hydroxyl-terminated, low-molecular-weight polyester, respectively.

Figure 12 presents the coefficients of friction for the four tapes, with coatings containing the various binders, in contact with the Ni–Zn ferrite pin as a function of load. The compositions with nitrocellulose (tape 5) and hydroxyl-terminated, low-molecular-weight polyester (tape 8) exhibited considerably lower coefficients of friction than did those with the other two binders over the entire load range. The composition with cellulose acetate (tape 7) resulted in the highest coefficient of friction at loads of 0.25 to 1.0 N. It, however, had a very low coefficient of friction at a load of 0.1 N. All the tapes in figure 12 revealed very low coefficients of friction at loads of 0.1 N or less.

Figure 13 presents the coefficients of friction for the four tapes as a function of the number of passes. The tapes that contained nitrocellulose (tape 5) and hydroxyl-terminated, low-molecular-weight polyester (tape 8) exhibited low friction and small changes in friction with the number of passes. The tapes that contained poly (vinyledene) chloride (tape 6) and cellulose acetate (tape 7) binder, however, exhibited a decrease in friction when repeated passes were made.

Not only the friction behavior of tapes, but also the morphology of tape surfaces is influenced by the binder composition. Figures 14 to 17 present scanning electron micrographs of the as-received surfaces and the wear tracks of tapes 5 to 8. These figures clearly reveal that the morphology of the tape surface is strongly influenced by the composition of the binder. Comparison of the as-received surfaces indicates that the degree of enclosure of the oxide particles by the binder due to sliding actions was in the following order of tapes: $8>7>6>5$. However, coefficient of friction of the tapes was in the following order of tapes: $5<8<6<7$. Figures 14 to 17 also suggest that the composition of the binder is an important factor controlling the smoothness of the coating and the degree of enclosure of the oxide particles by the binder.

Conclusions

As a result of sliding friction experiments conducted with various magnetic tapes in contact with a Ni–Zn ferrite hemispherical pin in air, the following conclusions were drawn:

1. The friction behavior of magnetic tapes can be divided into two categories by the nature of the deformation of the tape. In elastic contacts the coefficient of friction decreases as the load increases. In plastic contacts the coefficient of friction increases as the load increases. The coefficient of friction in elastic contacts is considerably lower than that with contacts whose deformation was plastic.
2. Composition of the binder is an important factor controlling the friction properties, morphology, and microstructure of tapes. Comparison of four tapes with different binders revealed that coefficients of friction of the tapes were lowest for nitrocellulose and increased in the order hydroxyl-terminated, low-molecular-weight polyester; poly (vinyledene) chloride; and cellulose acetate. The degree of enclosure of the oxide particles by the binder due to sliding actions was highest for the tape with the hydroxyl-terminated, low-molecular-weight polyester and decreased in the order cellulose acetate, poly (vinyledene) chloride, and nitrocellulose.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, September 1, 1983

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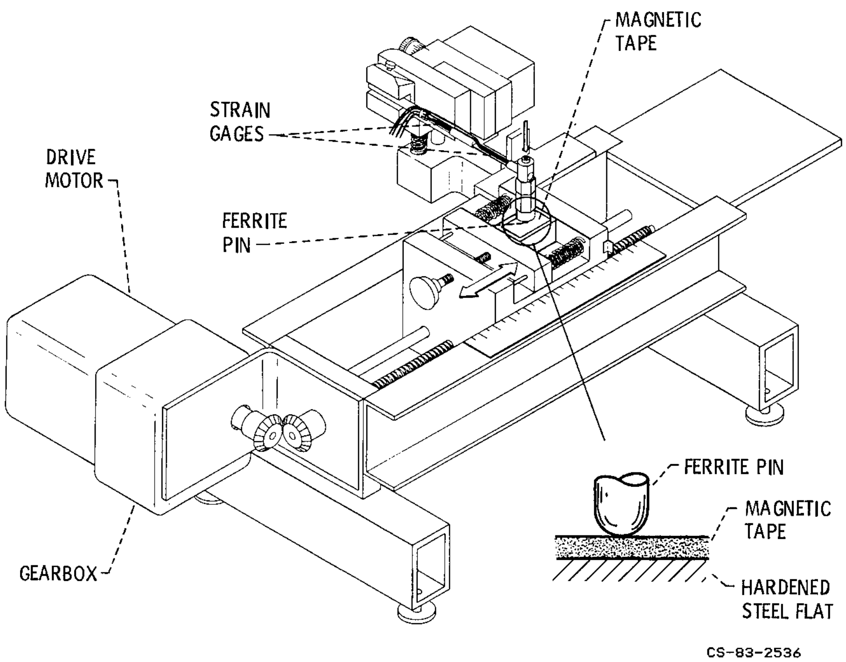


Figure 1. – Friction and wear apparatus.

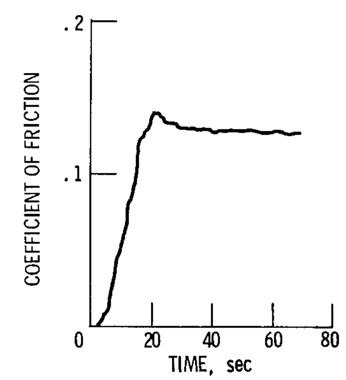
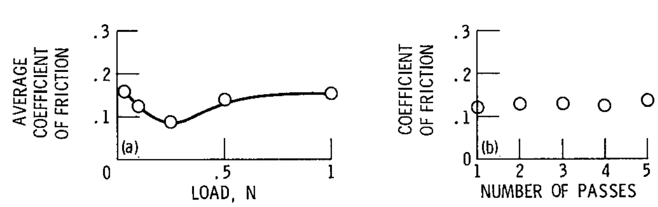
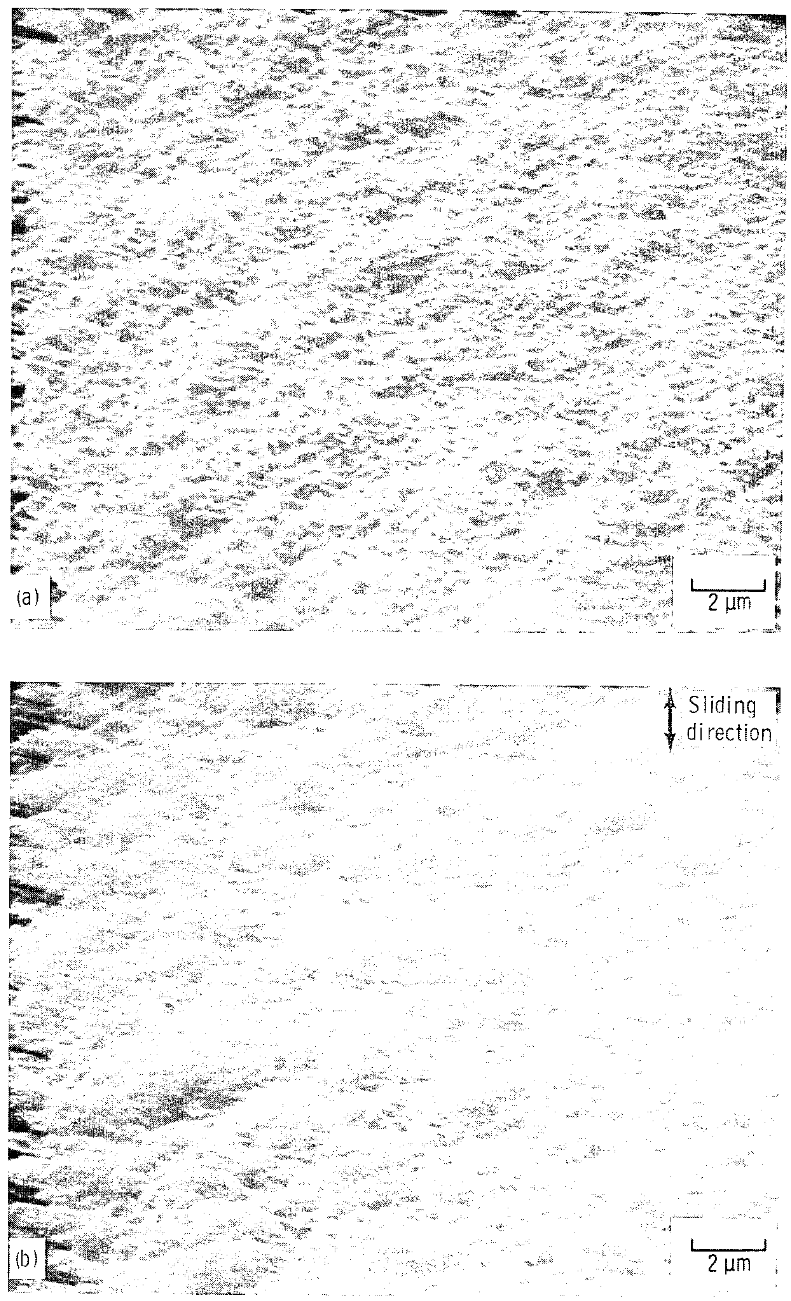


Figure 2. – Coefficient of friction as function of sliding time for Ni-Zn ferrite pin sliding on magnetic tape (tape 1 in table I). Normal load, 0.5 N; sliding velocity, 1.5 mm/min; relative humidity, 40 percent, temperature, 23° C.



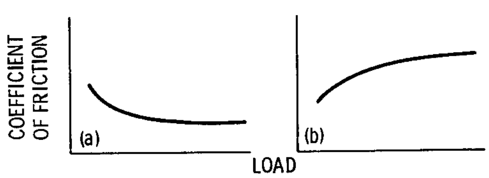
(a) Load (single-pass sliding). (b) Number of passes (load, 0.5 N).

Figure 3. – Coefficient of friction for Ni-Zn ferrite pin sliding on magnetic tape (tape 1 in table I) as function of load and number of passes. Sliding velocity, 1.5 mm/min; relative humidity, 40 percent; temperature, 23° C.



(a) As-received surface. (b) Wear track after 5 sliding passes (load, 1.0 N).

Figure 4. – Scanning electron micrographs of as-received surface and wear track on magnetic tape (tape 1 in table I) after 5 passes in sliding contact with Ni–Zn ferrite pin. Normal load, 1.0 N; sliding velocity, 1.5 mm/min; relative humidity, 40 percent; temperature, 23° C.



(a) Elastic contacts. (b) Plastic contacts.

Figure 5. – Schematic representation of effect of load on coefficient of friction of spherical hard pin sliding on soft solid (ref. 13).

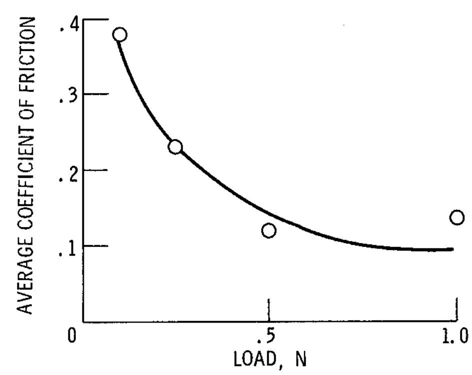
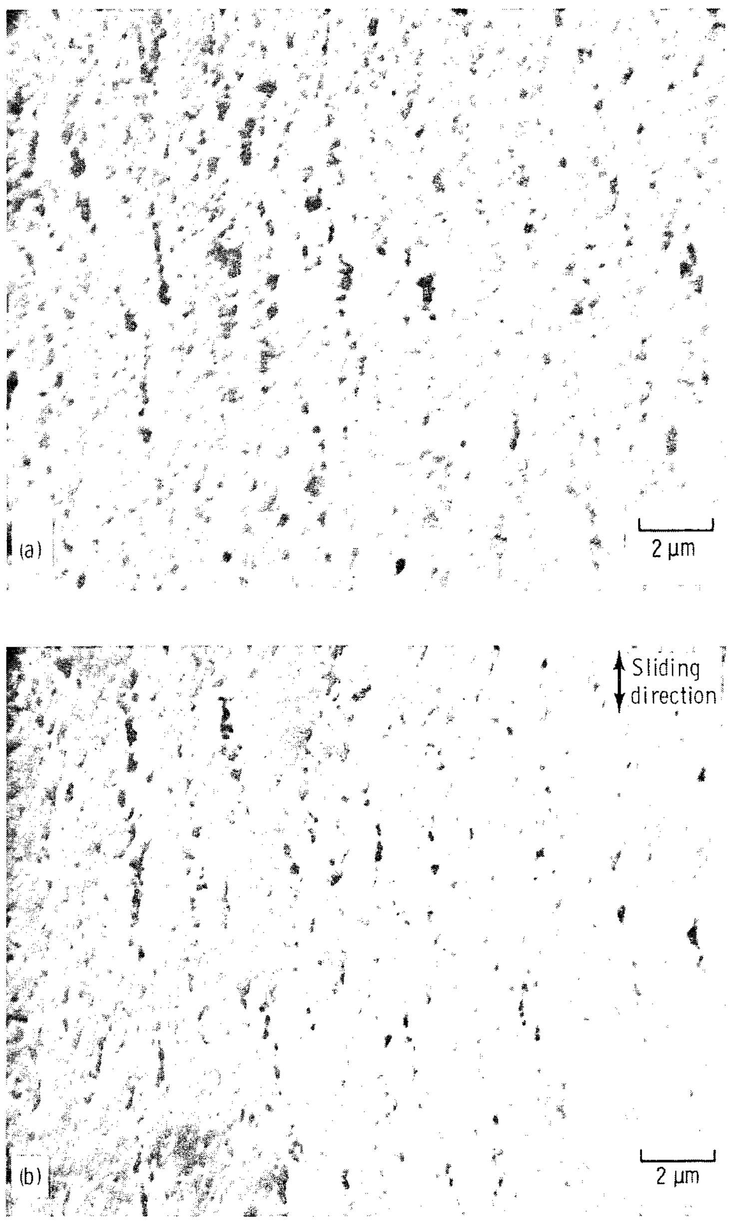
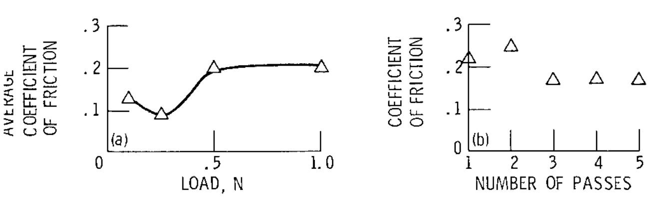


Figure 6. – Coefficient of friction for Ni–Zn ferrite pin sliding on polyester backing of tape 1 as function of load. Sliding velocity, 1.5 mm/min; relative humidity, 40 percent; temperature, 23° C.



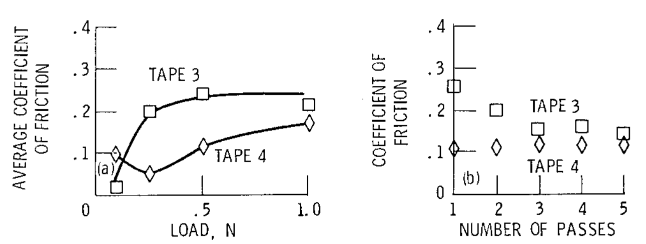
(a) As-received surface. (b) Wear track after five sliding passes (load, 1.0 N).

Figure 7. – Scanning electron micrographs of as-received surface and wear track on magnetic tape (tape 2 in table I) after 5 passes in sliding contact with Ni-Zn ferrite pin. Normal load, 1.0 N; sliding velocity, 1.5 mm/min; relative humidity, 40 percent; temperature, 23° C.



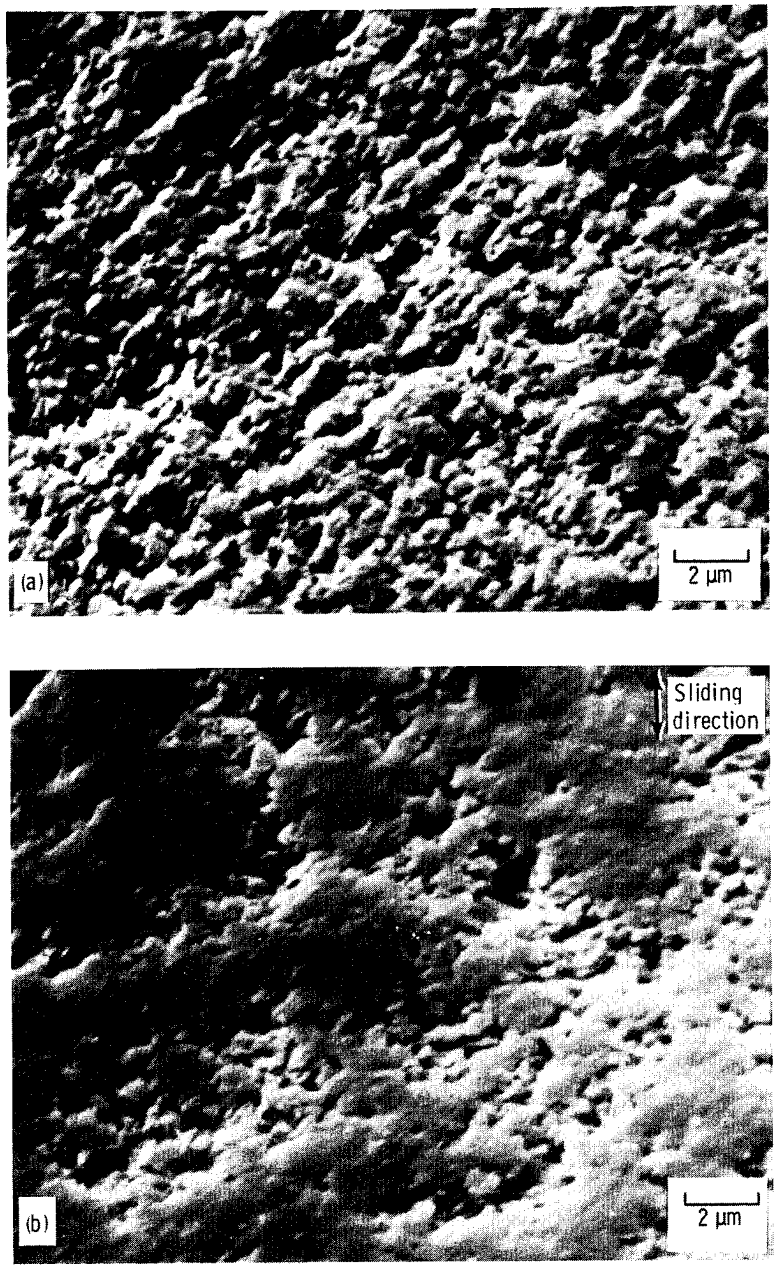
(a) Load (single-pass sliding). (b) Number of passes (load, 0.5 N).

Figure 8. – Coefficient of friction for Ni-Zn ferrite pin sliding on magnetic tape (tape 2 in table I) as function of load and number of passes. Sliding velocity, 1.5 mm/min; relative humidity, 40 percent; temperature, 23° C.



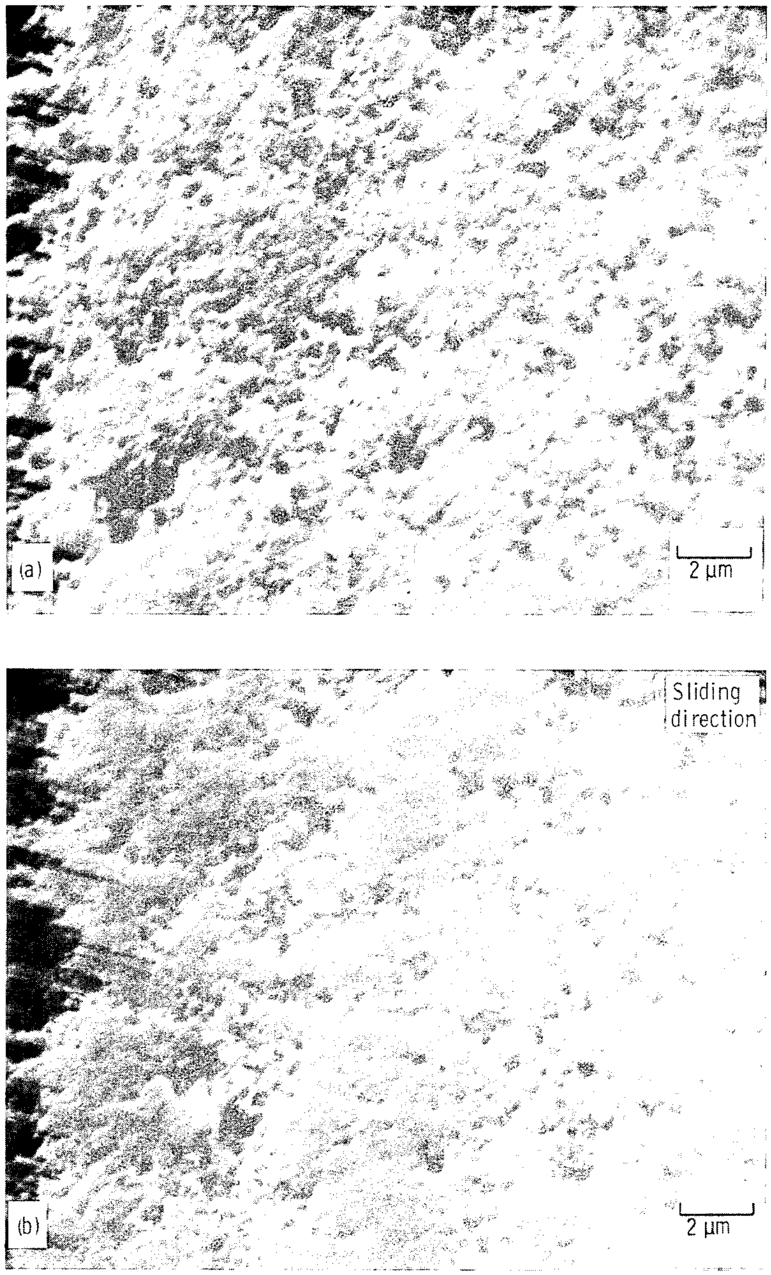
(a) Load (single-pass sliding). (b) Number of passes (load, 0.5 N).

Figure 9. – Coefficient of friction for Ni-Zn ferrite pin sliding on magnetic tapes (tapes 3 and 4 in table I) as function of load and number of passes. Sliding velocity, 1.5 mm/min; relative humidity, 40 percent; temperature, 23° C.



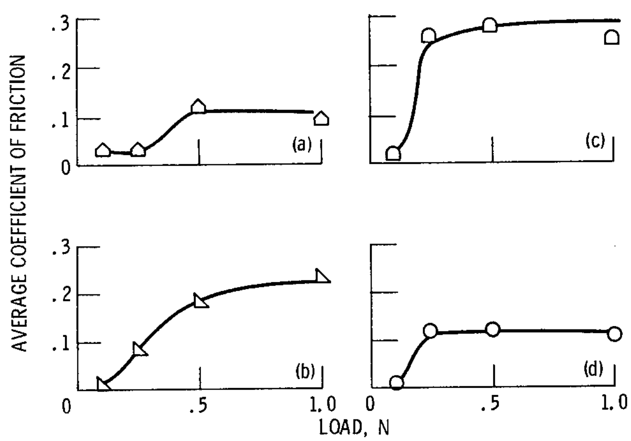
(a) As-received surface. (b) Wear track after 5 sliding passes (load, 1.0 N).

Figure 10. – Scanning electron micrographs of as-received surface and wear track on magnetic tape (tape 3 in table I) after 5 passes in sliding contact with Ni–Zn ferrite pin. Normal load, 1.0 N; sliding velocity, 1.5 mm/min; relative humidity, 40 percent; temperature, 23° C.



(a) As-received surface. (b) Wear track after 5 sliding passes (load, 1.0 N).

Figure 11. – Scanning electron micrographs of as-received surface and wear track on magnetic tape (tape 4 in table I) after 5 passes in sliding contact with Ni-Zn ferrite pin. Normal load, 1.0 N; sliding velocity, 1.5 mm/min; relative humidity, 40 percent; temperature, 23° C.



(a) Binder, nitrocellulose and polyester-polyurethane (tape 5).
(b) Binder, poly (vinyledene) chloride and polyester-polyurethane (tape 6).
(c) Binder, cellulose acetate and polyester-polyurethane (tape 7).
(d) Binder, hydroxyl-terminated, low-molecular-weight polyester resin (tape 8).

Figure 12. – Coefficient of friction for Ni–Zn ferrite pin sliding on magnetic tapes having CrO_2 magnetic particles and fatty acid ester lubricant (tapes 5 to 8 in table I) as function of load. Sliding velocity, 1.5 mm/min; relative humidity, 40 percent; temperature, 23° C.

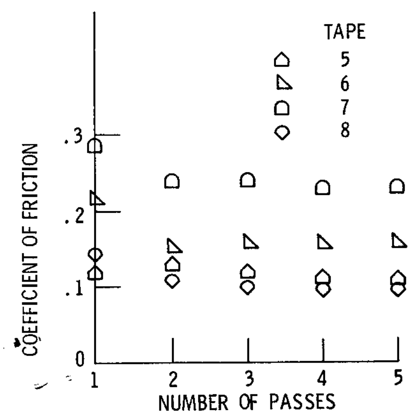
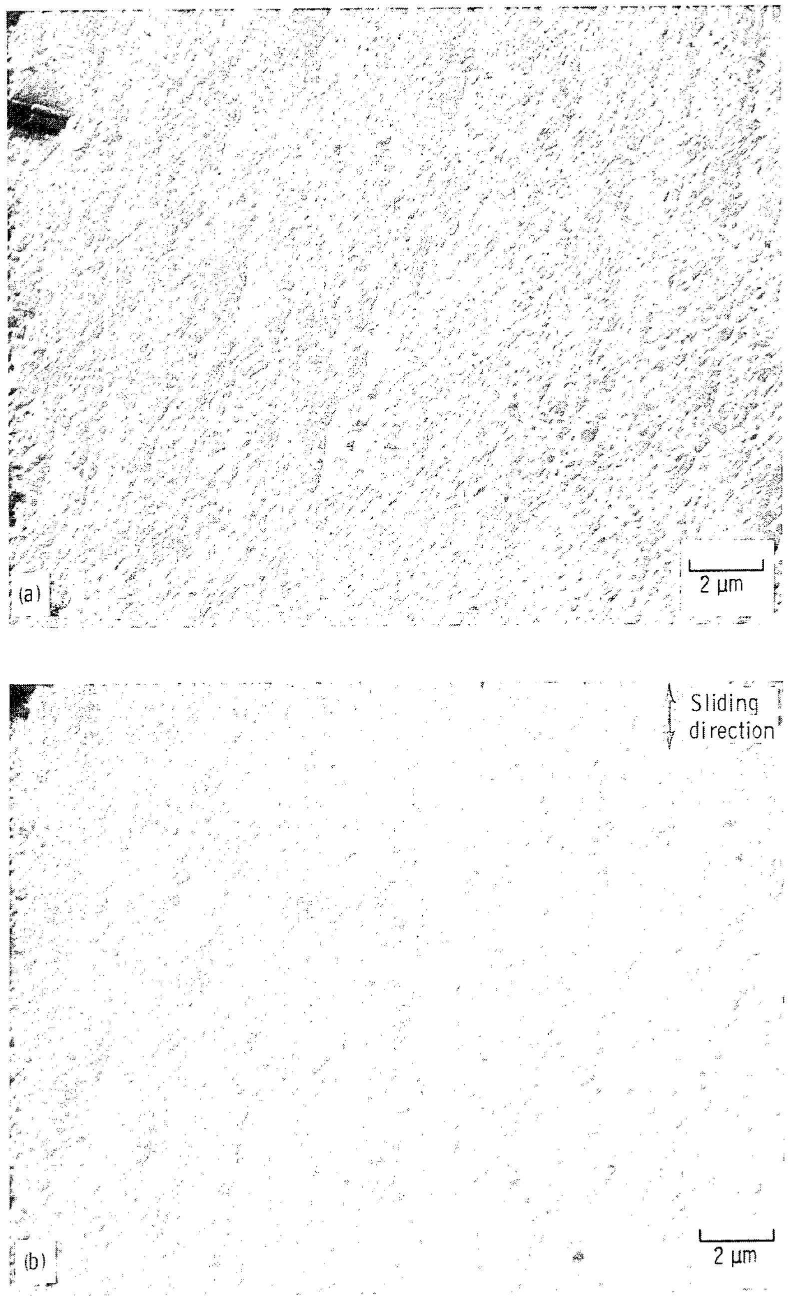
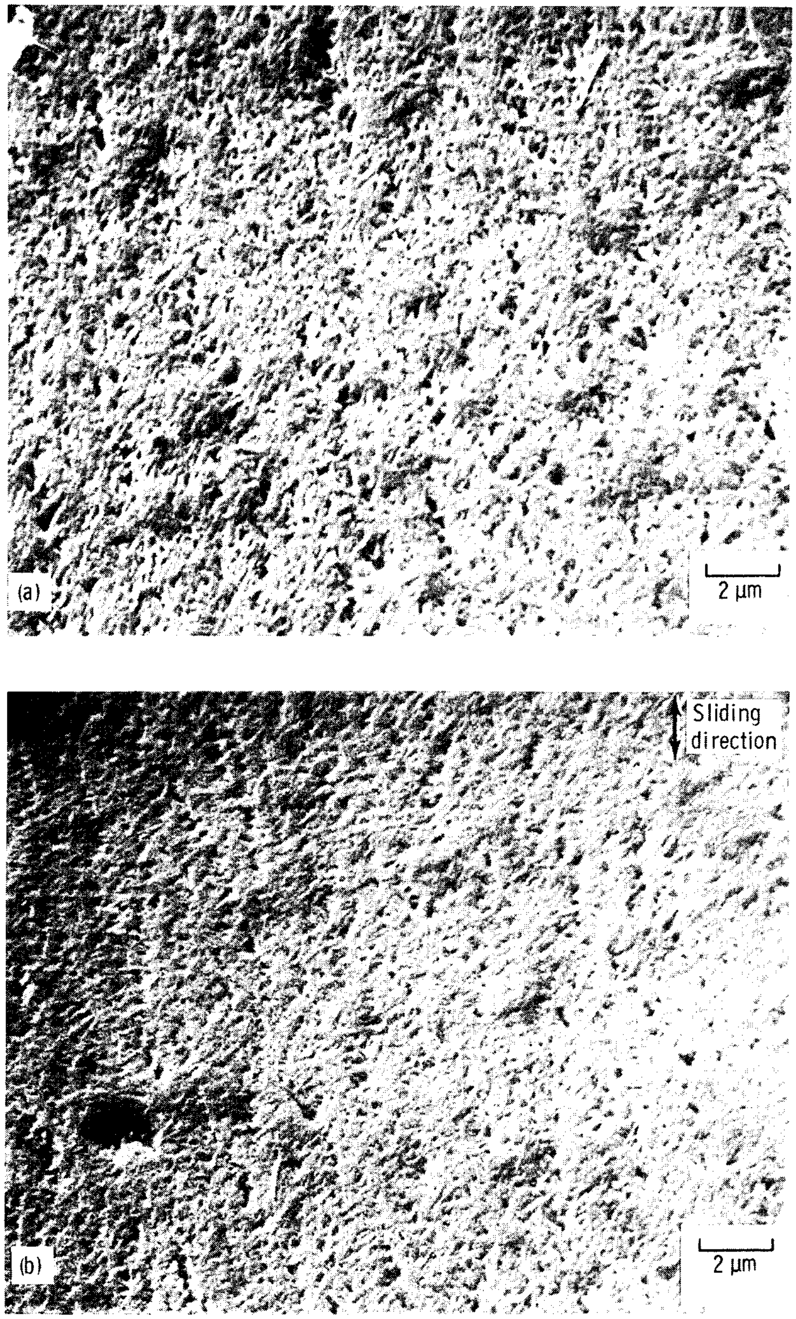


Figure 13. – Coefficient of friction for Ni–Zn ferrite pin sliding on magnetic tapes having CrO_2 magnetic particles and fatty acid ester lubricant (tapes 5 to 8 in table I) as function of number of passes. Normal load, 0.5 N; sliding velocity, 1.5 mm/min; relative humidity, 40 percent; temperature, 23° C.



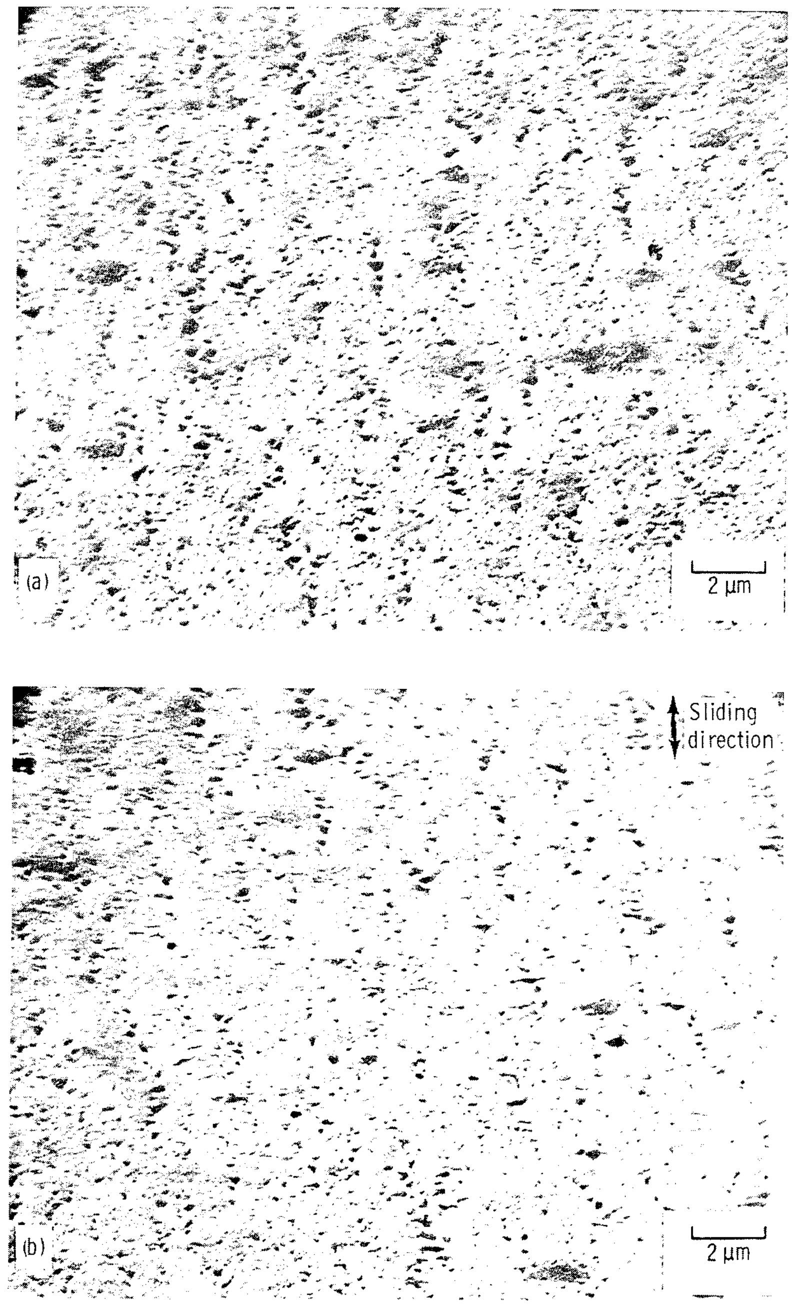
(a) As-received surface. (b) Wear track after 5 sliding passes (load, 1.0 N).

Figure 14. – Scanning electron micrographs of as-received surface and wear track on magnetic tape (tape 5 in table I) after 5 passes in sliding contact with Ni–Zn ferrite pin. Normal load, 1.0 N; sliding velocity, 1.5 mm/min; relative humidity, 40 percent; temperature, 23° C.



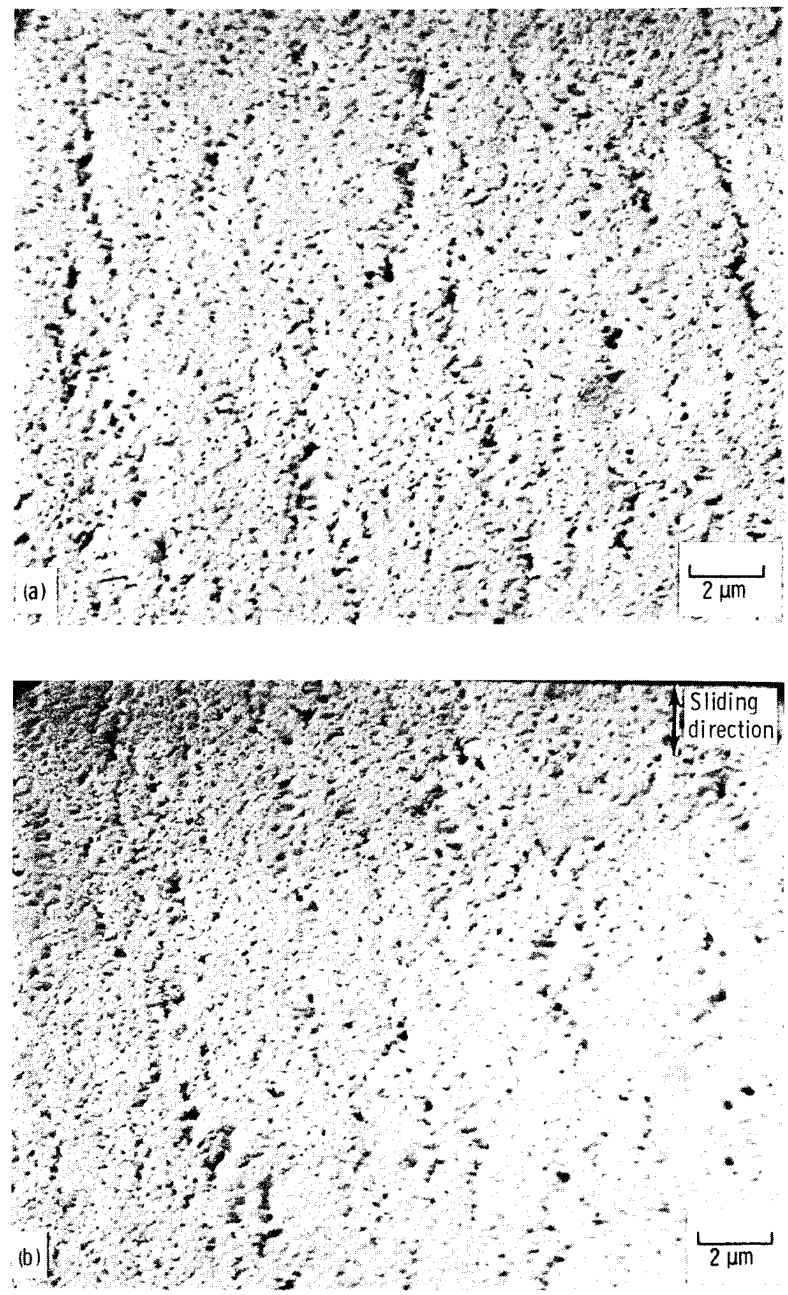
(a) As-received surface. (b) Wear track after 5 sliding passes (load, 1.0 N).

Figure 15. – Scanning electron micrographs of as-received surface and wear track on magnetic tape (tape 6 in table I) after 5 passes in sliding contact with Ni–Zn ferrite pin. Normal load, 1.0 N; sliding velocity, 1.5 mm/min; relative humidity, 40 percent; temperature, 23° C.



(a) As-received surface. (b) Wear track after 5 sliding passes (load, 1.0 N).

Figure 16. – Scanning electron micrographs of as-received surface and wear track on magnetic tape (tape 7 in table I) after 5 passes in sliding contact with Ni–Zn ferrite pin. Normal load, 1.0 N; sliding velocity, 1.5 mm/min; relative humidity, 40 percent; temperature, 23° C.



(a) As-received surface. (b) Wear track after 5 sliding passes (load, 1.0 N).

Figure 17. – Scanning electron micrographs of as-received surface and wear track on magnetic tape (tape 8 in table I) after 5 passes in sliding contact with Ni-Zn ferrite pin. Normal load, 1.0 N; sliding velocity, 1.5 mm/min; relative humidity, 40 percent; temperature, 23° C.

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15. Supplementary Notes

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16. Abstract

Friction and morphological studies were conducted with magnetic tapes contacting a Ni-Zn ferrite hemispherical pin in laboratory air at a relative humidity of 40 percent and at 23° C. The results indicate that the binder plays a significant role in the friction properties, morphology, and microstructure of the tape. Comparisons were made with four binders: nitrocellulose; poly (vinyledene) chloride; cellulose acetate; and hydroxyl-terminated, low-molecular-weight polyester added to the base polymer, polyester-polyurethane. The coefficient of friction was lowest for the tape with the nitrocellulose binder and increased in the order hydroxyl-terminated, low-molecular-weight polyester resin; poly (vinyledene) chloride; and cellulose acetate. The degree of enclosure of the oxide particles by the binder was highest for hydroxyl-terminated, low-molecular-weight polyester and decreased in the order cellulose acetate, poly (vinyledene) chloride, and nitrocellulose. The nature of deformation of the tape was a factor in controlling friction. The coefficient of friction under elastic contact conditions was considerably lower than under conditions that produced plastic contacts.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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