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Influence of Jet Printing Inks on Wear

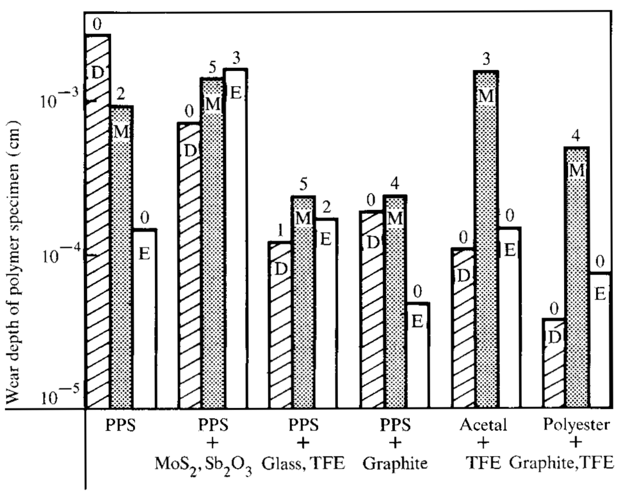
Abstract: This communication reports the results of wear tests performed to determine the influence of jet printing inks on the wear of several polymer-metal pairs, which were known to be compatible with the inks. It is shown that these inks generally tend to increase wear beyond that occurring in a dry state. The principal reason for this increase was concluded to be the adverse influence that the inks have on the establishment of a beneficial transfer film on the metal surface.

Introduction

Pumps used to circulate ink in jet printers present two special wear concerns: only materials which are compatible with the inks can be selected for the wearing elements; the inks may influence the wear behavior of the materials. The compatibility of materials with jet inks has been investigated by others [1]. This paper reports the results of a study of the influence of jet inks on the wear of materials that are known to be compatible with the inks.

In this study a series of sliding wear tests were performed on several different metal-polymer pairs, with and without ink present. Both the amount and nature of the wear produced were considered.

Figure 1 Wear resulting from tests lasting 3×10^4 cycles. The amount of slider wear is indicated by a number over the bar representing polymer wear in accordance with the following code: 0, no wear; 1, scratches; 2, 0.03–0.3 μm; 3, 0.3–0.5 μm; 4, 0.5–1.3 μm; and 5, 1.3–2.5 μm. The letters D, M, and E indicate dry, magnetic ink, and electrostatic ink.



Materials studied

Three types of polymers were used in the study: acetal, polyester, and polyphenylene sulfide (PPS). All the acetal and polyester specimens tested contained fillers. The acetal specimens contained tetrafluoroethylene (TFE) fiber (10%), whereas the polyester contained a mixture of TFE and graphite fibers (15% and 30%, respectively). Several versions of PPS were tested: unfilled, glass- and TFE-fiber filled (25% and 15%, respectively), MoS_2- and Sb_2O_3-powder filled (33% and 27%, respectively), and graphite-fiber filled (20%). Based on swell tests, these polymers were known to be compatible with at least one and generally both of the inks used in the study. The polyester material was not compatible with the magnetic ink used in these tests.

The metal used was 302 stainless steel, which was known to be compatible with the inks in terms of corrosion. Its hardness was 270 kg/mm^2.

The stainless steel wear specimens were in the form of 1.27-cm diameter spheres with a surface roughness of 0.05 to 0.10 μm peak-to-valley. The polymer specimens were in the form of thick slabs (approximately 2.5 cm by 1.2 cm by 0.5 cm). Whereas the samples were obtained from both casting and molding processes, the wear surfaces were machined prior to testing and had a nominal surface roughness of 0.4 μm peak-to-valley.

Two types of inks were investigated. One was an electrostatic ink, an almost neutral aqueous solution (pH $\approx$ 7) consisting of 77% by weight H_2O, 10% anti-crusting

(a) (b) (c)

Figure 2 Topography of wear scars in the polyester at 1000 × magnification with the material dry (a), with magnetic ink (b), and with electrostatic ink (c).

agent, 5% dyes, and the remainder mixed organics. Its viscosity at room temperature was approximately 2 mPa·s, and its surface tension was 40×10^{-3} N/m.

The second was magnetic ink, a slightly acidic solution (pH of 5) consisting of approximately 50% H_2O, 17% mixed organics, and 33% magnetite particles. The primary size of the magnetite particles was in the range of 15 nm with a typical aggregate size of 150 nm. The viscosity was approximately 12 mPa·s; and the surface tension, 35×10^{-3} N/m.

Test method

The wear tests were performed on an oscillating ball-plane friction and wear apparatus. The stainless steel sphere was attached to a cantilevered beam, which had strain gauges attached for measuring both the friction and normal force. In this apparatus, the sphere is referred to as the slider. A flat polymer specimen was mounted on a carriage which oscillated approximately sinusoidally underneath the slider. The normal load was achieved by pressing the slider against the largest flat surface of the polymer specimen. The test apparatus allowed for control of both stroke amplitude and frequency of oscillation.

Prior to each test the specimens were cleaned, first by a mild abrasive technique, then washed with a detergent, and next rinsed thoroughly with water. The specimens were finally rinsed with alcohol and allowed to dry. In the case of the metal, the mild abrasive technique consisted of brushing the surface with a solution of water and submicron Al_2O_3 powder; for the polymer specimen, wet polishing with 600 grit paper.

The tests were performed both with the wear surfaces clean and dry and with the flat specimen's surface flooded with ink. To achieve the flooding, a small dike was placed around the edges of the sample.

The tests were conducted with a normal load of 50 g at 1.6-mm stroke length, and at a rate of 500 cycles per minute. The average sliding speed was 2.5 mm/s.

A new slider and a new area on the polymer specimen were used for each test. Test durations were 7×10^3, 15×10^3, and 30×10^3 cycles. At the conclusion of each test the specimens were cleaned of loose debris and of ink when it was used. Wear was then measured by means of a Talysurf [2] profilometer, and the wear scars were examined by optical microscopy.

Results

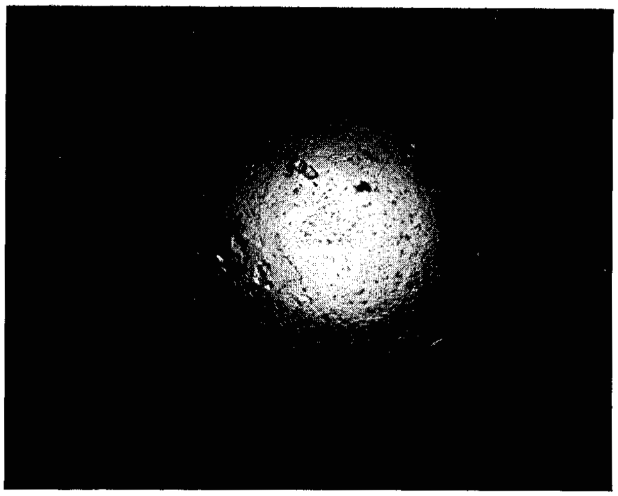
The volume of wear of the polymer specimens was approximately linearly dependent on the number of cycles. The depth of the wear scars on polymer specimens after 3×10^4 cycles is shown in Fig. 1, and the code used to indicate the wear of the stainless steel sliders is described in the caption.

Except for the polymer that contained no anti-wear or anti-friction additives, the inks generally tended to increase wear on the polymer with the magnetic ink usually causing significantly more wear than the electrostatic ink. Wear occurred on the stainless steel in all cases in which the magnetic ink was used and in two cases in which the electrostatic ink was used—the glass-filled PPS and the MoS_2- and Sb_2O_3-filled PPS.

Optical examination of wear scars on the polymer specimens (see Fig. 2) also revealed that, under dry conditions, some flow, smearing, and adhesion effects were always present, with the scar having moderate to severe roughness. These characteristics were most severe for unfilled PPS. When inks were used, the flow and smearing disappeared, and the polymer specimens had a much smoother appearance. However, when magnetic ink was used, fine scratches were always observed on the polymer specimen. With electrostatic ink scratches were only evident in one case, for the MoS_2- and Sb_2O_3-filled PPS.

Optical examination of the steel sliders revealed that under dry conditions polymer material typically adhered to the slider but not when inks were used (see Fig. 3). In addition, the slider surface was scratched in all cases in

(a)



(b)

Figure 3 Wear scar on slider (a) shows adhered polymer material; adhered polymer is absent from slider (b).

which either the magnetic ink was used or the glass and MoS_2- and Sb_2O_3-filled PPS samples were used.

Table 1 shows the coefficients of friction obtained for the oscillatory tests.

Influence of transfer film on wear

The general trend of increased wear with both inks can be explained in terms of transfer film phenomena. The influence of these films on wear and friction has been known; in particular, their importance in the wear of polymer-metal pairs has been reported [3–5]. A transfer film is a coating of material from one surface of a sliding pair generated on the surface of the other during sliding. Typically, these coatings result from adhesive interactions of the two samples, and the establishment of a stable and uniform transfer film results in a mild wear regime with reduced wear rates. But perturbation in the film's characteristics or its removal (absence) results in increased wear rates. Consequently, the increase in wear when inks are used can be explained on the basis of the inks' interference with the formation of such films. Specifically, the ink reduces or eliminates the adhesion necessary for the development of a transfer film. Such behavior is consistent with the general tribological rule that the presence of contamination or a lubricant at the interface tends to reduce adhesion between the surfaces.

This explanation is supported by the appearance of both surfaces at the conclusion of the wear tests. As noted, under dry conditions the adherence of the polymer to the slider was observed [see Fig. 3(a)], but not under inked conditions. Moreover, the large plastic deformation associated with adhesive wear mechanisms and the continual exchange of material between the surfaces typically result in a smeared appearance of the wear scar. Consequently, the smearing evident in the polymer wear scars under dry conditions [see Fig. 2(a)] indicates adhesive behavior, whereas the smooth scars under inked conditions do not [see Figs. 2(b), 2(c), and 3(b)].

This explanation for the general influence of ink on the wear of the polymer-metal system studied is also supported by additional tests utilizing a rotating disk-pin apparatus. In this case the disk was of stainless steel and the pin, a polymer. Wear generated in such an apparatus is less sensitive to transfer film effects; transfer films are less likely to be developed because of the relatively large size of the wear path on the metal surface and the small polymer contact surface. This point was confirmed in the present case by examination of the steel disk after the dry tests, which revealed little or no transfer materials.

Because of this lower sensitivity to transfer films, it was anticipated that there would be less difference between the inked and dry tests with this apparatus, which was the case. This implies that the reason for the general trend seen in the oscillatory tests is related to transfer film phenomena.

Further evidence for this explanation is found in the results obtained with the unfilled PPS. In this case, a stable, uniform transfer film was not developed in the dry case. Rather, a coarse adhesive wear situation developed resulting in severe wear. In this case the use of ink resulted in a dramatic reduction in adhesion, and the wear decreased markedly.

Other factors affecting wear

The magnetic ink, in addition to its influence on transfer film generation, also introduced an abrasive wear mechanism resulting from the magnetite particles contained in this ink. Their effect is clearly evident in the topography of the wear scars produced [see Fig. 2(b)]. Fine scratches were observed on both the polymer and metal surfaces in every case that the magnetic ink was used. While the abrasive action of the magnetite in the ink was anticipated, since it is a known abrasive, its significance and magnitude was not. However, a review of Fig. 1 shows that in all cases the additional abrasive action resulted in significantly increased wear both on the metal and the polymer.

Scratches similar to those found when the magnetic ink was used were seen in only two cases when the electrostatic ink was used. These exceptions occurred when the polymers contained abrasive fillers—the glass- and TFE-filled PPS and the MoS_2- and Sb_2O_3-filled PPS. In the case of the former material, the glass fibers are abrasive. In the latter, the abrasion is attributed to the Sb_2O_3, which is moderately hard.

Two of the fillers, glass and Sb_2O_3, tended to increase slider wear as a result of abrasion. However, wear of the polymer was much reduced with the glass-TFE mixture, as can be seen by comparing the dry test results for the two filled materials and the unfilled PPS. This we attribute to the greater resistance to wear of the glass in the glass- and TFE-filled PPS.

While the fillers tested generally tended to improve the wear of the polymer in the dry state, only the graphite filler indicated any significant benefit in the inked state. It is speculated that this behavior results from the improved lubricity which graphite exhibits in the presence of moisture [6].

Friction

In addition to the effects that jet printing inks have on wear, they also affect friction. A review of Table 1 shows that they substantially reduced friction of the PPS material and also reduced that of the other materials as well.

The PPS materials in general had poorer friction characteristics than polyester or acetal. In addition to their typically high coefficients of friction when dry, these materials had a tendency for stick-slip, which was eliminated when ink was used. The PPS materials also had a general tendency for greater friction variations both dry and with inks, the significance of which was evident in the case of a small magnetic ink piston pump. Pressure fluctuations were noted when filled PPS materials were used. However, when the materials were changed to TFE-filled acetal, these fluctuations were eliminated, with the implication that friction variations were their cause [7].

Summary

This study demonstrated that jet printing inks influence both the wear and friction of polymer-metal sliding pairs. In terms of wear this influence can be a negative one. For polymer-metal systems in which transfer films develop to provide good wear behavior, the inks tend to prevent the formation of these films and increase wear. An additive to the ink to reduce wear is desirable in such cases. For polymer-metal systems in which severe adhesion occurs, however, the inks reduce wear by reducing the adhesion. Further, the results of this study demonstrate that the fine magnetite particles contained in magnetic ink can cause significant abrasive wear.

In terms of friction the inks may be considered as lubricants. In general they tend to reduce and moderate frictional behavior.

The different material pairs tested exhibited different wear rates. The TFE- and graphite-filled polyester had the best overall characteristics, followed by graphite-filled PPS and TFE-filled acetal. The glass- and TFE-filled PPS are not considered good materials because of the abrasive nature of the glass. Of the various fillers used, graphite appears to be the most appropriate for use with these aqueous inks.

Table 1 Summary of friction data.

Material	*Dry*	*Magnetic ink*	*Electrostatic ink*
PPS	0.40–0.60	0.12–0.20	0.16
PPS + MoS_2, Sb_2O_3	0.40–0.60	0.16–0.24	0.20–0.50
PPS + glass, TFE	0.12–0.18	0.10–0.18	0.16
Acetal + TFE	0.12–0.18	0.10–0.18	0.08–0.16
Polyester + TFE, graphite	0.18–0.19	0.12	0.16

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