

Observations on the Coefficient of Friction of Polypropylene Film

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Synopsis

Data are presented relating the time change of the coefficient of friction of cast polypropylene films to changes in film density and concentration of surface lubricant. It is shown that during aging the density of polypropylene increases, thus causing a decrease in the friction coefficient. It is also shown that although the lubricant added to the polymer will diffuse to the surface of copolymer films, no diffusion occurred in polypropylene films.

INTRODUCTION

The coefficient of friction (COF) of thin (<2 mil) polypropylene films is a physical property of major concern to film manufacturers. Because friction affects film wrapping and handling characteristics, an understanding of this property is necessary to allow manufacture of films with the desired COF.

Films having different friction or slip levels can be prepared by extruding and quenching at thermal conditions necessary to vary the surface roughness or gloss of the film. A second method of controlling the COF is to incorporate in the polymer an amphipathic or slip additive such as stearamide, oleamide, or behenamide.

The additive is thought to diffuse^{1,2} to the film surface, where it acts as a lubricant which decreases the COF. It is possible to vary the magnitude of the COF by varying the concentration of slip additive. An alternate method of controlling COF would be to hold the concentration of slip additive constant but vary the type of additive to regulate the lubricity. Use of an homologous series of fatty acid amides has been shown^{3,4} to be effective in giving different COF levels.

The effect of additive migration and film aging on the change of COF are described in this investigation. Data are reported which show that additive migration did not occur in polypropylene films but did occur in propylene-ethylene copolymer films. Other data are presented which show a dependence of COF on film density.

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EXPERIMENTAL

Preparation of Cast Films

The films used in this study were made from Escon polypropylene and propylene-ethylene copolymer by extruding the polymer at melt temperatures of 500–550°F. and quenching on a chill roll at temperatures between 60 and 90°F. All films were extruded at a speed of 140 ft./min. to a nominal gauge of 1 mil. Docosenoamide was used as the slip additive in all samples.

Determination of Surface Concentration of Amide

A sheet of film (28 × 28 in.) was taped along each edge to a vertical stainless steel plate (32 × 36 in.) which had a lip at the bottom edge to allow wash liquid to drain into a weighing bottle. The film was washed three times with chloroform applied from a glass wash bottle. The total volume of wash liquid was less than 90 ml. During initial washing trials it was found that contact of the chloroform with rubber, polyethylene, and some tape adhesives caused extraction of materials which interfered with the amide analysis. Use of a glass wash bottle and Scotch brand transparent tape eliminated interfering materials from the analysis.

The wash liquid was collected in a weighing bottle and evaporated to dryness. The residue was redissolved in a known volume of chloroform and the amide concentration determined from the intensity of the characteristic infrared peak occurring at 1600 cm.^{-1} . The deviation of the surface concentration determination was 3×10^{-4} mg./in.² at the 2σ level.

Determination of Film Density

The density of all film samples was calculated from the refractive index of the film determined by a technique described elsewhere.⁵

COF Determination

The static coefficient of friction of the films was determined on a Thwing-Albert Egan slip tester according to ASTM test D1894-61T with the use of two modified sleds. Sled A was a metal block, 1 × 2 in., weighing 100 g. and wrapped with a low-density foam rubber. Sled B had the same geometry as sled A but was wrapped with a medium-density sponge rubber. The use of two sleds resulted from changes in the test procedure at this laboratory during the period of the study described herein.

DISCUSSION

In the polyolefin film industry the decrease of the COF of polypropylene film during aging is generally assumed to be caused by the slow diffusion of slip additive or amide to the film surface. As the concentration of additive on the surface increases, the COF of the film decreases. If for some reason the additive does not diffuse to the surface, the COF remains high. Initially, this theory was assumed valid, and accordingly this study was

directed toward determining the relation between COF development and the rate at which additive diffused to the film surface.

Analysis of the surface additive washed from polypropylene films containing increasing weights of amide showed that contrary to the above assumption the surface concentration of slip additive remained essentially constant during 4 days of aging while the COF of the films decreased. Data illustrating this effect are shown in Table I. It can be seen that the change in COF became more pronounced as the concentration of surface amide increased.

TABLE I
Concentration of Amide on Polypropylene Film Surface

Amide added to polymer, %	Film age, days	Concentration of amide on one surface, mg./in. ² × 10 ⁴	Static COF (sled A)
0.06	0	12.2	0.36
	1	15.1	0.33
	2	16.9	0.34
	3	10.5	0.31
	4	15.5	0.30
0.08	0	21.0	0.34
	1	20.4	0.30
	2	12.3	0.27
	3	18.6	0.24
	4	20.8	0.24
0.10	0	17.8	0.38
	1	24.2	0.25
	2	26.7	0.23
	3	33.6	0.18
	4	22.3	0.19
0.12	0	58.5	0.19
	1	46.4	0.13
	2	42.1	0.09
	3	46.4	0.07
	4	65.3	0.06

Because the data were in contradiction to the commonly assumed diffusion mechanism, and the results of Hastings⁶ who used an infrared technique to demonstrate amide migration in copolymer films, a comparison was made of the surface additive changes during aging of polypropylene and propylene-ethylene copolymer films. This was done to establish the validity of the washing technique. In Figure 1 are plotted data showing the change in slip additive on the surface of cast polypropylene and copolymer films. From these data it can be seen that concentration of surface amide on the copolymer film increased linearly during the first 7 days of aging, while the additive in the polypropylene film remained constant after an initial decrease. This decrease, which was observed in

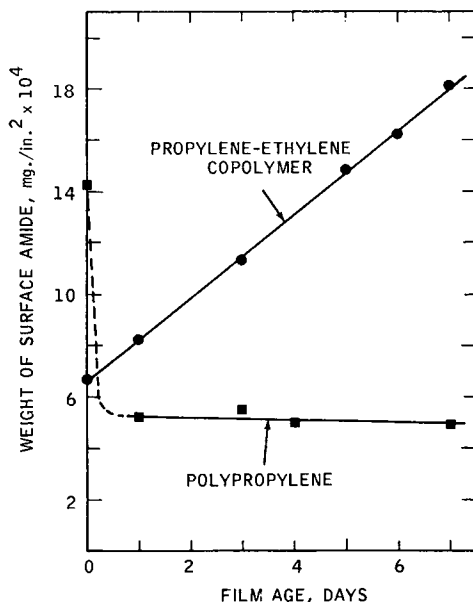


Fig. 1. Changes in surface amide during film aging.

films washed within 20 min. after fabrication, is attributed to extraction of amide from the fresh film.

From the data in Table I, it is also evident that the concentration of surface amide increases as the amount of additive in the polymer increases. The extent of the concentration change of surface additive on polypropylene films containing up to 2% amide is shown in Table II. From a graph of these data (Fig. 2) it can be seen that there is a break in the plot forming two lines of different slope which intersect at a surface concentration of about 80×10^{-4} mg./in.². The reason for the two lines is not yet known. Assuming an area of 28 Å.² per amide molecule, calculations indicate that

TABLE II
Comparison of Surface Concentration and Total Added Amide

Amide in polymer, %	Available weight amide in polymer, mg./in. ² × 10 ^{4a}	Surface amide, mg./in. ² × 10 ⁴ (single surface)
0.04	58.3	15.6
0.06	87.5	21.8
0.08	111.6	22.0
0.10	145.8	31.9
0.18	262.4	60.2
0.50	729.0	115.2
1.0	1458	178.9
1.5	2187	242.8
2.0	2916	298.3

^a Calculation of the weight of available amide is based on a film density of 0.8900 g./cm.³ and a film thickness of 0.001 in.

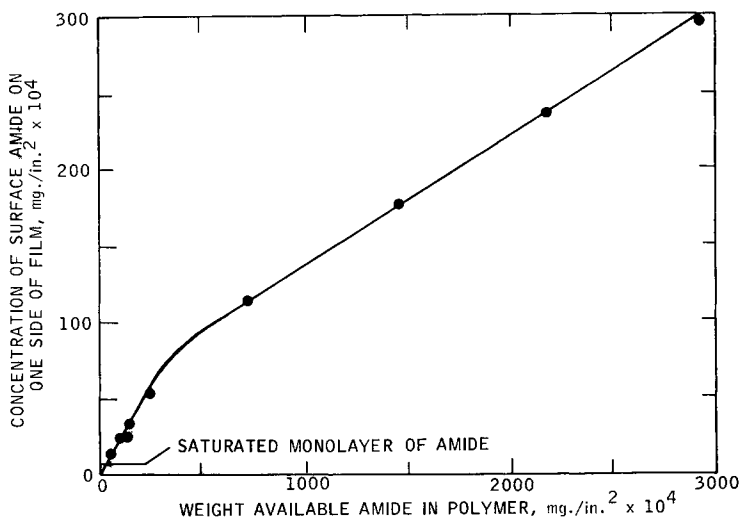


Fig. 2. Changes in surface amide as weight of available amide increases.

12×10^{-4} mg. of amide is sufficient to give a saturated monolayer on the film surface. This low surface concentration was exceeded in all of the films used in this work, indicating that a multiple layer of additive was formed on the film surface. The high concentrations of surface additive may be the result of condensation of additive vapors on the film surface during quenching on the chill roll.

The initial surface additive concentrations shown in Table I, i.e., film age 0 days, were obtained on films 4–6 hr. after extrusion. Since it was possible that the diffusion process might be rapid enough to occur in less time, a film was washed as soon as possible after extrusion. From the data in Table III, it can be seen that no increase of surface additive was measured within 9 minutes after extrusion. It is probable that the amide is deposited on the polypropylene surface during the extrusion process either by a rapid diffusion of the melted additive or a plating-out mechanism occurring by condensation of additive volatilized during extrusion.

In addition to incorporating a lubricating additive in polyolefin film, it is

TABLE III
Surface Amide on Fresh Film

Film age	Concentration of surface amide, $\text{mg./in.}^2 \times 10^4$
9 min.	30.0
17 min.	32.4
67 min.	28.2
76 min.	27.9
6.5 hr.	24.9
1 day	27.0
4 days	24.3

common practice also to add an antiblock additive. These additives are usually fine particles of an inert material such as silica, talc, and metallic silicates. Comparison (see Table IV) of the COF of films containing slip additive with and without antiblock shows that although both films had similar amounts of additive on their surfaces, only the films containing an antiblock agent were slippery. The films containing no antiblock additive had COF values greater than 1, while films with antiblock additive had COF values less than 1 and proportional to the concentration of surface amide.

TABLE IV
COF of Films with and without Antiblock Additive

Additive, %		Concentration of amide on one side of film, mg./in. ² × 10 ⁴	COF after 5 days aging (sled A)
Amide	Antiblock		
0.06	0	15.5	1
0.06	0.06	15.2	0.30
0.08	0	43.2	1
0.08	0.06	39.2	0.24
0.10	0	50.3	1
0.10	0.06	52.4	0.19

Coefficient of Friction and Film Density

From the data presented, it can be seen that the COF of polypropylene films decreases as the films age without any evidence of diffusion of slip additive to the surface. It will be shown in this section that the decrease of the COF occurred because of a change in the viscoelasticity of the film.

Examination of the literature on friction phenomena shows that the frictional force F between two plastic surfaces is proportional to the load W raised to a power, i.e., $F = KW^n$.⁷ The exponent n , which varies between the limits of 1 for a plastic deformation and $2/3$ for an elastic deformation, depends on the viscoelastic character of the plastic. It has also been shown⁸ that the COF is related to the viscoelastic properties of specific shear strength S and yield pressure P of the plastic by the equation $\mu = S/P$

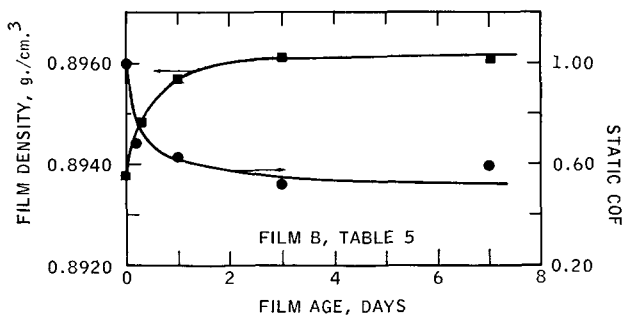


Fig. 3. Change of density and COF of polypropylene without added amide.

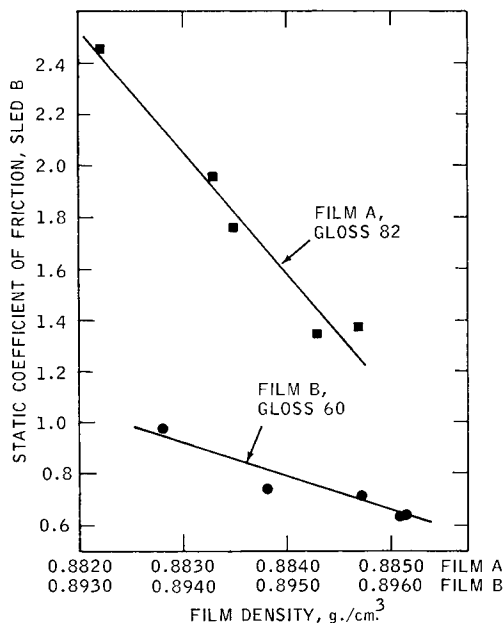


Fig. 4. Decrease of COF with increasing density of polypropylene films containing no amide.

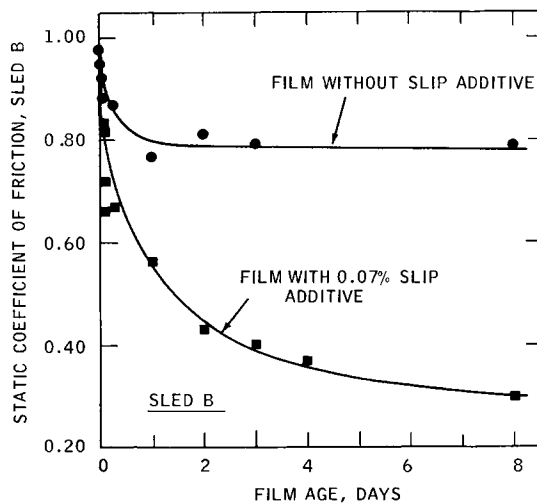


Fig. 5. Changes of COF for films with and without slip additive.

with the shear strength, yield pressure, and ratio of these quantities decreasing as the temperature of the plastic is increasing.

A study of the physical properties of polypropylene films showed that the film density was the only time-dependent property which would affect the viscoelasticity. Measurements of the density of cast polypropylene films

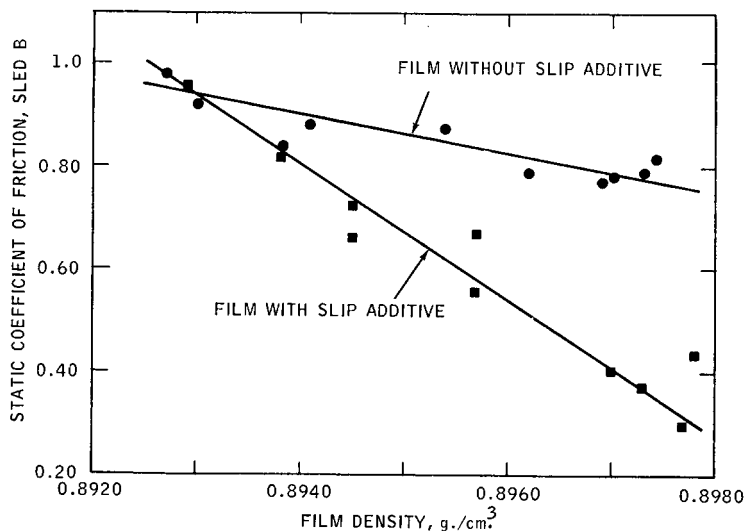


Fig. 6. Decrease of COF with increasing density of polypropylene films with and without slip additive.

at times as short as 1 min. after extrusion showed that the density increases rapidly during the first 24 hr. of aging and more slowly during the next 6 days.

From measurement of the COF and density changes in a polypropylene film containing no slip additive, it was found that although any possible diffusion process had been eliminated the COF of the film decreased as the film density increased. The change of density and COF of two polypropylene films (film A, gloss 82; film B, gloss 60) containing no slip additive are compared in Table V. From the change in properties of Film B shown graphically in Figure 3, it can be seen that greatest changes in density and COF occurred during the first 24 hr. of aging. From a plot of COF as a function of density in Figure 4, it can be seen that the COF decreased linearly as the density increased.

In Figure 5, data are plotted to compare the change of COF in films with and without slip additive. The initial COF values of the films were the

TABLE V
Change of Density and COF during Aging of
Polypropylene Film Containing No Amide

Film age	Film A, gloss 82, sled B		Film B, gloss 60, sled B	
	Static COF	Density, g./cm. ³	Static COF	Density, g./cm. ³
5 min.	2.45	0.8822	0.97	0.8938
6 hr.	1.95	0.8833	0.74	0.8948
1 day	1.76	0.8835	0.71	0.8957
3 days	1.37	0.8847	0.63	0.8961
7 days	1.34	0.8843	0.63	0.8961

same but during aging the friction of the film with slip additive decreased to a much lower level than the friction of the film with no additive. Since the additive did not diffuse to the surface, the large decrease in COF can be attributed to the density increase of the film plus the added lubricating effect of the surface additive. A graph of the decrease of COF with increasing density of the same films is shown in Figure 6. For both films the COF was a linear function of density.

CONCLUSIONS

By measuring and comparing the density, COF, and surface additive concentration data presented in this report, it has been possible to show the relation between film properties affecting COF. It has been shown that the decrease of the friction of polypropylene films is not caused by diffusion of slip additive to the film surface, but rather by an increase in density occurring during film aging. The absence of diffusion may be peculiar to polypropylene since this phenomenon was shown to occur in copolymer film. Since measurements have shown that the increase in density in polypropylene films also occurs in copolymer films, it appears that both the increase in density and the slip additive diffusion contribute to the COF change in copolymers.

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Résumé

Des résultats sont présentés en vue de relier d'une part les variations avec le temps du coefficient de friction de films coulés de polypropylène aux variations de densité du film et à la concentration en lubrifiant de surface d'autre part. Au cours du vieillissement, la densité du polypropylène s'accroît, causant ainsi une diminution du coefficient de friction. On montre également que bien que le lubrifiant additionné au polymère puisse diffuser à la surface des films de copolymères, néanmoins aucune diffusion ne se présente au sein des films de polypropylène.

Zusammenfassung

Es werden Daten bezüglich der Abhängigkeit des Reibungskoeffizienten von gegossenen Polypropylenfilmen von der Filmdichte und der Konzentration des Oberflächen-gleitmittels vorgelegt. Während der Alterung nimmt die Dichte von Polypropylen zu, was eine Abnahme des Reibungskoeffizienten verursacht. Weiters wird gezeigt, dass das dem Polymerfilm zugesetzte Gleitmittel zwar zur Oberfläche von Kopolymerfilmen diffundiert, dass jedoch bei Polypropylenfilmen keine Diffusion auftritt.

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