

TECHNICAL BULLETIN: CONSIDERATIONS ON COF



1 Introduction

The coefficient of friction (COF) is a dimensionless scalar value which describes the resistance put by the surface of a material to a sliding object.

In conversion processes (Printing, Lamination, Cutting) and packaging (Form, Fill and Seal [FFS]), plastic films come into contact with many surfaces (rollers, guides, forming necks, etc.) on which are generated frictional forces that tend to oppose the film displacement.

As the slip resistance gets higher (high COF values), the presence of the following processing defects can be observed:

1. Generation of surface scratches and marks which affect film appearance and especially its gloss.
2. Deformation and thinning of the film; this defect can be more evident in the loss of color overlay in printing (off-register).
3. Film break with the subsequent interruption of production process.

To avoid these defects, slip additives are added into materials used in the manufacture of films for automatic packaging applications, in order to reduce the coefficient of friction.

In polyethylene, the addition of slip agents allows to reduce the value of COF from 0.7 – 0.8 to 0.1.

Typically, automatic packaging process requires kinetic film – film COF values around 0.2.

Slip additives are substances which are partially compatible with PE, which means that – during polymer recrystallization – the slip agent migrates or is driven towards the free surface of the film.

In general, polyethylene films can be classified according to their coefficient of friction as:

Type	Slip agent content (ppm)	COF
Without slip agent	0	0.7 to 0.8
Low Slip	500	> 0.4
Medium Slip	1000	0.2 to 0.4
High Slip	1500	0.1 to 0.2

Note: Film thickness: 25µm.

2 COF measurement

Typically, two parameters are reported:

- Static: indicates the resistance level put by a material to start moving an object.
- Kinetic: indicates the resistance level put by a material to keep moving an object at constant speed.

The coefficient of friction is obtained based on the guidelines of ASTM D1894 or British Standard BS824. Both standards measure the resistance put by a film to a sliding sled with normalized dimensions and weight.

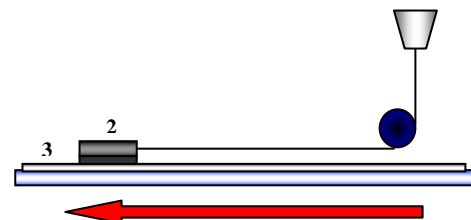


Figure 1: Scheme of the device used to determine the coefficient of friction of plastic films (1: Load cell, 2: Rubberized sled, 3: Film).

Both standards differ in the following factors:

Parameter	Units	ASTM D1894	BS 824
Sled weight	g	200	700
Speed	mm/min	150	800
Displacement	mm	150	500

As a consequence of these differences, both test methods yield different results. The coefficient of friction values measured according to BS 824 are between 7 and 120% higher than those obtained with ASTM D1894.

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3 Slip additives

There is a wide variety of substances which can be used as slip promoting agents in polyethylene. These include:

- Amides
- Silicones
- PE waxes.
- Teflon

Commercially, amides (especially oleamides and erucamides) are the most widely used as slip additives for polyolefins.

Below are listed the main types of amides used as slip agents.

Amide	Formula	Melting point (°C)
Oleamide (O)	$C_{17}H_{33}C(O)NH_2$	66 - 72
Erucamide (E)	$C_{21}H_{41}C(O)NH_2$	75 - 82
Stearamide (SR)	$C_{17}H_{36}C(O)NH_2$	96 - 102
Behenamide (BR)	$C_{21}H_{44}C(O)NH_2$	108 - 112
Oleyl palmitamide (OP)	$C_{18}H_{35}NH(O)C_{16}H_{31}$	60 - 66
Stearyl erucamide (SE)	$C_{18}H_{37}NH(O)CC_{21}H_{41}$	70 - 75
Ethylene bis-stearamide (EBS)	$C_{17}H_{36}C(O)NH(CH_2)_2NH(O)CC_{21}H_{36}$	140 - 145
Ethylene bis-oleamide (EBO)	$C_{17}H_{33}C(O)NH(CH_2)_2H(O)CC_{17}H_{33}$	115 - 120

The addition of 500 ppm of erucamide reduces COF of a LDPE film to values close to 0.1, while an equivalent dose of behenamide provides a COF value of 0.8. This difference is attributed to a linear structure present in the behenamide molecule that forms crystals with larger surface resistance.

Some references report that blending oleamides and erucamides promotes a synergistic effect in the blend; however, studies describe that this type of mixture has a lower decay rate of COF through time and, additionally, as the proportion of oleamide increases the tendency to block the film gets higher.

4 Influence of other additives

The presence of other additives in PE formulation affects the performance of slip agents.

4.1 Antiblock

In general, antiblock additives modify film surface regularity. This alteration in the film surface properties has shown to contribute to reduce COF.

Synthetic silicas are highly porous materials which can absorb amides, reducing their ability to promote slippage. It has been found that addition of 3000 ppm of silica in LDPE can completely eliminate the slip effect of 500 ppm of erucamide.

Some types of talc used as antiblock agents, have a synergistic effect when they are blended with erucamide.

4.2 Antistatics

Commonly, glyceryl monostearate (GMS) is used as antistatic agent for films. Because antistatic agent action requires, as slip agent, migration of the compound to film surface, the combined presence of both additives produces a phenomenon of competition to reach the free surface of the film. The direct consequence of this mechanism of competition is that both the slip and antistatic agent are less effective.

As an example, COF values obtained in a LDPE film with different formulations of erucamide and glyceryl monostearate (GMS) are shown below.

Erucamide content (ppm)	GMS content (ppm)	COF @ 10 h
500	0	0.12
500	1000	0.38
500	2500	0.50
500	5000	0.70
0	5000	0.85

4.3 Molecular structure

PE slip properties are particularly affected by density. As PE density increases, the fraction of material that is incorporated into crystal structures gets higher, which reduce the coefficient of friction of materials in its natural form as well as added with slip agent.

Other molecular parameters which affect COF are:

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- Linearity of the molecule: for resins of the same density and melt flow rate, LLDPE has higher COF than LDPE (0.85 vs. 0.77).
- Catalytic system: linear polyethylene obtained by metallocene catalysts exhibit higher COF values compared to products obtained with Ziegler Natta catalysts.

4.4 Combination of materials

Different combinations of materials (blends, laminations, coextrusions, coating, etc.) induce several effects on film slip performance.

In coextruded structures, the slip agent has the additional option of migrating to the contact surface between the materials which take part in the film, to be absorbed by an adjacent layer. Figure 2 shows COF evolution for two PE three-layer coextruded films, in which 1000 and 2000 ppm have been incorporated in only one of the external surfaces of the structure.

The increase in COF in these examples can only be explained by slip additive migration to layers without additives which compose the structure.

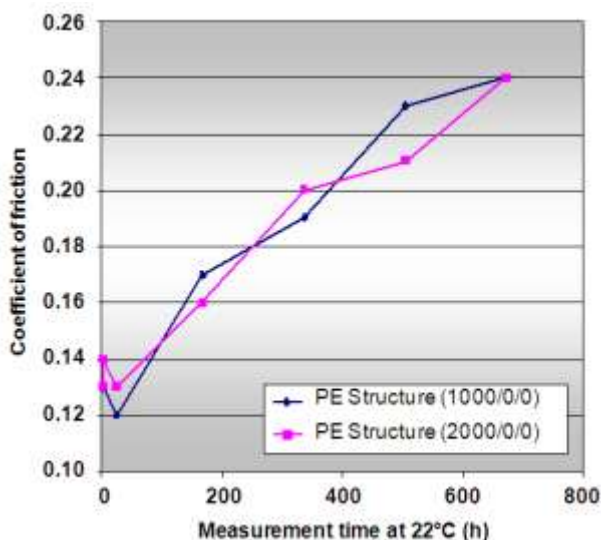


Figure 2: COF variation of three-layer coextruded structures with 1000 and 2000 ppm (Layer A has 1000 and 2000 ppm of erucamide).

Studies have shown that in coextruded structures with ionomers in sealing layers, slip agent migration takes place not only to the free surface of the film, but also between the layers to which the additive has not been added.

Due to the affinity of polar amides with polar polymers such as ionomers, coextruded structures with these materials exhibit the following effects:

- Preferential migration of the amide to the face that contacts the polar resin, when additive is incorporated into non-polar material (eg PE).
- Preferential migration of the amide to the outer surface of the polar material, when additive was incorporated into the material which composing this layer.

As a result of this interlayer migration, some specialists suggest that coextruded films with ionomers should not be laminated neither before 5 days nor after 20 days on which it was extruded.

It has been found that COF variation with storage temperature is higher in coextruded structures with non-polar polymers, (eg PE or PP) than in those that incorporate polar products (eg ionomers, polyesters, polyamides, acid copolymers).

5 Processing conditions

5.1 Extrusion

Winding tension is the extrusion variable which has the greatest effect on COF.

Works have shown that COF (both static and kinetic) has a second order ratio with regard to winding tension, as can be seen in the next figure.

The slip agent migration inhibition phenomenon generated by increasing winding tension is produced by the effect of reduction of free energy exothermic separation caused by high pressure between both faces of the film. Thus, instead of migrating to the faces of the film, the slip agent migrates from one surface to the other, reducing the effective concentration of slip agent required to have the desired COF.

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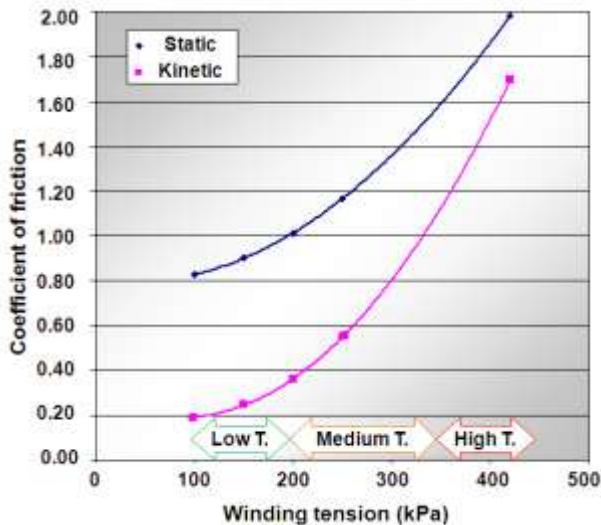


Figure 3: COF variation of a three-layer PE coextruded structure added with 2500 ppm of erucamide and 5000 ppm of silica.

Based on this mechanism, it is also possible to anticipate that in lines of extrusion, coextrusion, lamination, cutting, among others, which have center winders, a heterogeneous slip distribution could happen, with the highest COF as it goes towards the center of the roll.

Given the evidence of sliding problems arising from winding tension is recommended:

- Reducing tension applied by winder to a level that prevents occurrence of defects in the roll, such as the telescope type effect.
- Reinforcing additive resin base with a concentration of slip agent, adding small doses (200 to 250 ppm).

Finally, it is convenient to remember that extrusion temperature has an extremely low influence on COF, so it is not recommended to alter it.

5.2 Corona treatment

Treating film surface tends to increase COF due to:

- Generation of polar groups which increase attraction between layers.

- Steaming or burning slip additives, which migrate to film surface.

Due to these defects, the basic rule in film surface treatment (corona or flame) is that the unit designed for this purpose shall be located as close as possible to extrusion head. In this way, it is taken an advantage on the time required for the additive to migrate to the surface of the film.

Figure 4 shows a guide that allows establishing the power level to be used in the treater, to compensate the loss caused by slip agents.

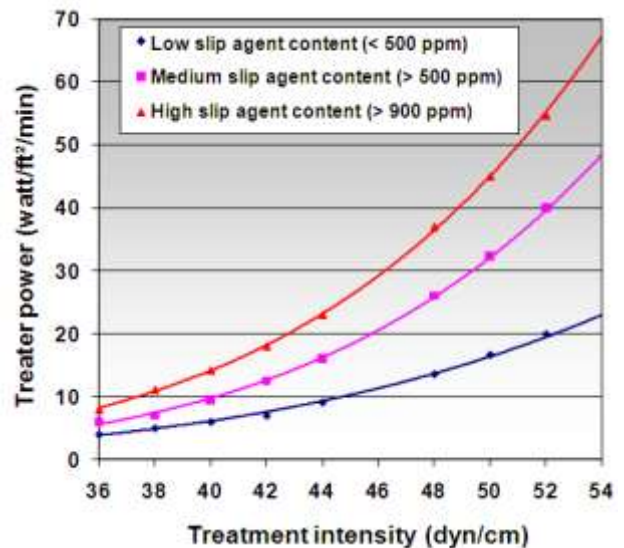


Figure 4: Guide to adjust the corona treater power, level of treatment required and slip agent content.

Blown LDPE or LLDPE	Use plotted data
HDPE	Power x 0.75
Polyester	Power x 0.75
Nylon	Use low slip agent content curve
Paper o cardboard	Power x 0.75
Blown PP	Use medium slip agent content curve
BOPP Copolymer	25 w/m ² /min
BOPP Homopolymer	55 w/m ² /min
Pearl BOPP	25 w/m ² /min
Flat LDPE or LLDPE	Power x 1.50
EVA	Use low slip agent content curve x 1.5
Metalized film	20 w/m ² /min
Metalized paper	20 w/m ² /min

5.3 Lamination

The heat applied by lamination rolls can contribute to increase COF. As an example, it was found that COF in a lamination film composed by two

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coextruded HDPE/EVA/ionomer increases from 0.25 to 0.5 after laminating at 65 °C (150 °F).

The laminating adhesives also have the disadvantage of “kidnapping” the slip agent which migrates to the surface of the film, increasing COF.

Laminations that have been manufactured at room temperature yield COF values from 0.25 to 0.30, while those in which pressing rollers’ temperature is 80 °C (176 °F), there is an increase of COF from 0.35 to 0.55. Fortunately, this increase is reversed after a few days of conditioning.

6 Storage conditions

Some studies consider storage temperature as the most influential factor on COF.

The increase in storage temperature has the ability to raise the rate of solubility of the polymer additive, which reduces the fraction of it that stays on the surface of the film. As a result of this mechanism, an increase of COF is experimented.

Figure 5 and 6 show COF evolution in different slip agents as a function of film storage temperature.

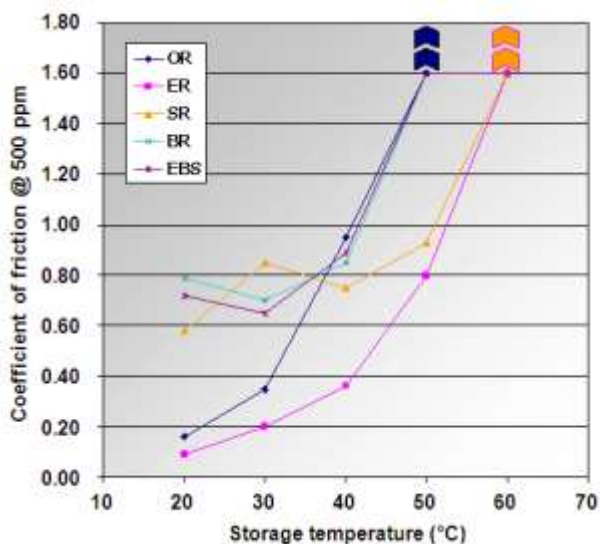


Figure 5: COF variation with respect to storage temperature for different slip additives in LDPE dosed at 500 ppm.

It is particularly interesting for erucamide, in which 1000 ppm doses attenuate the effect of increasing COF.

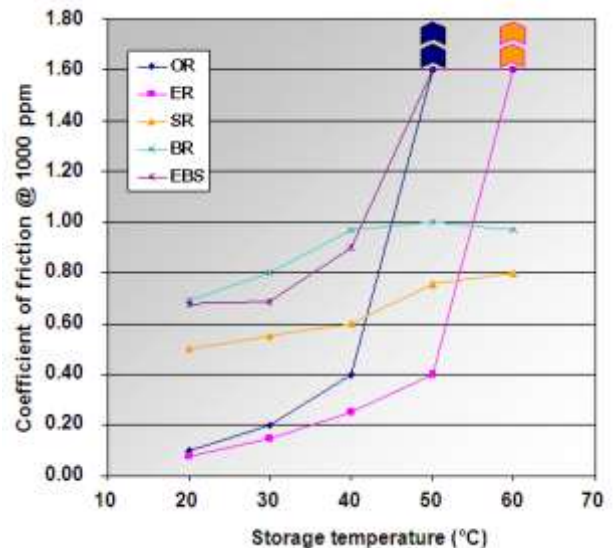


Figure 6: COF variation with respect to storage temperature for different slip additives in LDPE dosed at 1,000 ppm.

At high temperatures (60 °C) only stearamides and behexamides are effective, due to their saturated structure (without double bonds C = C) gives them a higher melting point.

In laminations commercialized in export markets, it has been found that COF value changes from 0.18 (measured after 10 days of laminating) to 0.40. A close monitoring of these dispatches showed that the upper litters of rolls stored in containers reach temperatures of 63 °C (145 °F), which is responsible for increasing the solubility of slip additive in polymer and thus, a COF augmentation.

Because changing storage temperature has no influence on total content of slip agent present in the film, the increase in COF experienced at high temperatures can be reduced or reversed by storing the film in less severe conditions. For example, in the case previously described, it was achieved, with storage of rolls at room temperatures, to reduce the COF from 0.4 to 0.25 within ten days.

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