

Roles of Slip Agent in Blown Film Extrusion of Linear Low Density Polyethylene

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Published online: 15 April 2018

To cite this article: Nur Haslina Nasirah Abdul Hadi, Mohd Fairuz Zainal Abidin and Raa Khimi Shuib. (2018). Roles of slip agent in blown film extrusion of linear low density polyethylene. *Journal of Engineering Science*, 14: 61–70, <https://doi.org/10.21315/jes2018.14.5>.

To link to this article: <https://doi.org/10.21315/jes2018.14.5>

Abstract: *In this work, the effects of different contents of slip agent (0, 800, 1,000, 1,200 and 1,500 ppm) on the surface friction and tensile properties of Linear Low Density Polyethylene (LLDPE) films were investigated. The mixture of LLDPE and slip agent was first compounded and palletised using twin screw extruder and subsequently processed into film using extrude blow film machine. Coefficient of friction (COF), tensile strength, elongation at break, Young's modulus and gel count of the produced film were investigated. It was found that COF, tensile strength and Young's modulus decreased with increase in contents of slip agent but the elongation at break was found to slightly increase. It was also found that the gel count increased as the contents of slip agent increased which might be due to remaining slip agent or contamination in the materials.*

Keywords: Slip agent, LLDPE, films, COF, tensile properties

1. INTRODUCTION

Linear Low Density Polyethylene (LLDPE) by far is the most commonly used material for commodity packaging due to its properties such as non-toxic, easily processible, reprocessible, cold-resistant, resistant to moisture, toughness and high tensile strength. However, typically LLDPE films surfaces are tacky and exhibit a high coefficient of friction (COF), which tend to stick to metals and to other components of the handling lines during their fabrication and use.¹ In order

to avoid this problem, especially on the packaging lines, the plastic films need to have a low level of friction. The required COF of the plastic films is commonly achieved by the use of the additive, which is called as a slip agent.^{2,3}

The main function of slip agent is to modify the surface properties of LLDPE films. Slip agent in LLDPE materials are used to bloom the film surface in order to reduce the COF.⁴ Slip agent is typically added during the mixing and extrusion stage of the resins and the additives. The slip agent are incompatible with the bulk polymer, therefore they are not bonded into the bulk polymeric matrix but are free to migrate to the surface after extrusion. The size of the molecule plays an important role in order to determine the ease of the slip agent to migrate through the bulk polymer to the surface. The molecular structure of slip agent can be modified by increasing the molecular chain length or by adding or subtracting the carbon atom. Addition of more atomic molecules increases the chain length and slows down the speed of migration and it also increases the compatibility with the bulk polymer.⁵

Multiple factors need to be considered to control the migration of the slip agent from the bulk polymeric matrix to the surface. The most important factor are slip agent amount.⁶ The incorrect amount of slip agent and poor processing might produce defects during printing, sealing and handling.⁷ In view of the large quantity of LLDPE produce worldwide for the film blowing market, it is of interest to investigate the roles of slip agent in blown film process. The objective of this work is to assess the effect of different contents of slip agent (0, 800, 1,000, 1,200 and 1,500 ppm) on the surface friction and tensile properties of LLDPE films.

2. EXPERIMENTAL

2.1 Materials

LLDPE copolymer with butane as a comonomer was used in this work. The properties of LLDE are shown in Table 1. LLDPE powder and Erucamide slip agent CAS 112-84-5 was provided by Petronas Chemicals Polyethylene Sdn Bhd (PCPSB).

2.2 Compounding Process

LLDPE virgin powder and slip agent were pre-mixed in a container and was placed on the rotating roller at approximately 250 rpm for at least three hours to homogenise the mixture. The slip agent content was varied from 0, 800,

1,000, 1,200 and 1,500 parts per million (ppm). The premixed of LLDPE and slip agent was dried in vacuum oven overnight at 40°C to remove moisture before compounded in a twin screw extruder (PSM 30 co-rotating twin screw extruder). The temperature profile was shown in Table 2. The screw speed was adjusted to 65 rpm. The premixed was then fed into the extruder hopper and extruded through the die, passed in a cold-water bath at 28°C and then pelletised.

Table 1: Properties of LLDPE.

Properties	Units	Test method	Value
Physical			
Melt flow rate (MFR)	g/10 min	ISO 1133	1.0
Mechanical			
Tensile strength at yield (MD/TD)	MPa	ISO 527-3	11/12
Tensile strength at break (MD/TD)	MPa	ISO 527-3	40/31
Elongation at break (MD/TD)	%	ISO 527-3	1,300
Elmendorf tear strength (MD/TD)	g/25µm	ISO 6383/2	160/400
Dart impact strength	g	ISO 7765-1: (A)	160
Other			
Clarity	%	ASTM D 1746	90
Gloss (45°)	GU	ASTM D 2547	52
Haze	%	ASTM D 1003	30
COF	–	ISO 8295	0.14

Table 2: Temperature profile of twin screw extruder.

Zone	Barrel set temperature (°C)	Melt temperature (°C)
1	170	170
2	175	175
3	180	181
4	180	180
5	185	185
6	185	189
7	190	196
8	190	189
9	195	199
Die	200	200

2.3 Blown Film Process

Fabrication of LLDPE film was carried out using extrusion blown film machine manufactured by Queen Machinery Co. Ltd. The LLDPE premixed was first dried in an oven overnight at 40°C to remove moisture before blown film. The following blowing conditions were employed: barrel temperature, Zone 1: 170°C, Zone 2: 175°C, Zone 3: 185°C; die temperature (Zone 4): 190°C; screw speed: 300 rpm and pull speed: 425 rpm. Extruded sheets were pulled using a take-up device and film thickness was maintained at about 0.03–0.045 mm.

2.4 Testing

2.4.1 COF

COF was determined using Twin Albert friction/peel tester. The testing was carried out according to ASTM D-1894. Sample was cut into 12.5 × 6 cm. The plastic film was then tape to the metal block equipped with a sponge rubber pad and subsequently pulled across a plane covered with sample film at a constant speed of 150±30 mm/min. Static and kinetic COF were measured and the average values of the three samples were reported.

2.4.2 Tensile test

Tensile test was carried out according to ASTM D 638 using an Instron Universal Testing Machine Type 3366. The gauge length and grip distance were kept constant at 50 mm and the crosshead speed was set at 50 mm/min. The tensile strength (TS), elongation at break (Eb) and Young's Modulus (E) of five samples of each composition were measured and the average values were reported.

2.4.3 Gel count

Gel count test was carried out by using image analyser (Metallurgical Microscopemeiji Image Analyzer) under 50× magnification. The film was cut into 10 × 10 mm size and placed on a glass microscope with a drop of silicon oil and covered with a glass covered slip. The gel count was recorded. Figure 1 shows example of gel that contains on plastic film.

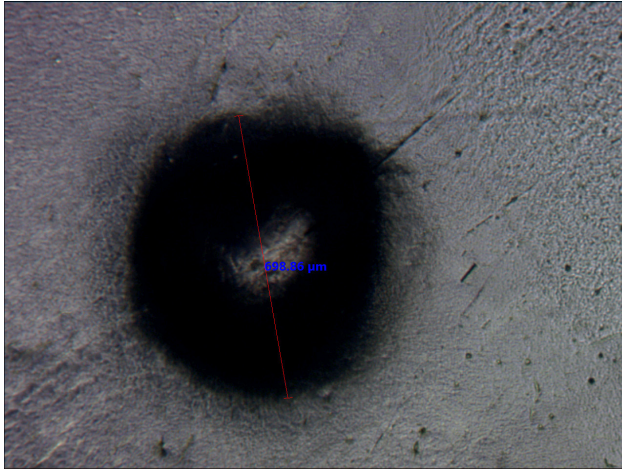


Figure 1: A gel on plastic film.

3. RESULTS AND DISCUSSION

3.1 COF

The COF of the LLDPE film at different contents of slip agent is shown in Figure 2. The COF decreased with increasing content of slip agent. Increasing content of slip agent increased the amides migration to the surface of the bulk matrix such that provides an internal reservoir of lubrication that occurs on the film surface shortly after exiting the die. Migration occurs because the slip agent has limited chemical compatibility and solubility in the LLDPE matrix. During processing, the amide is solubilized in the amorphous melt but after LLDPE cooled and it began to crystallise, the slip is literally squeezed out from the solidifying polymer matrix to the surface. On the surface, the amide forms a soft lubricating layer, filling in valleys and imperfections. This layer effectively separates adjacent film surfaces, preventing sticking and blocking and reduces the force required to move coated surfaces tangentially across one another, thereby lowering the COF.^{8,9} It can also be seen that static COF which is associated with the force needed to start moving an object was higher compared to kinetic COF which is the force needed to sustain movement with an average percentage difference of 12.84%. The difference between static and kinetic COF might arise from irregularities or surface contaminants.^{10,11}

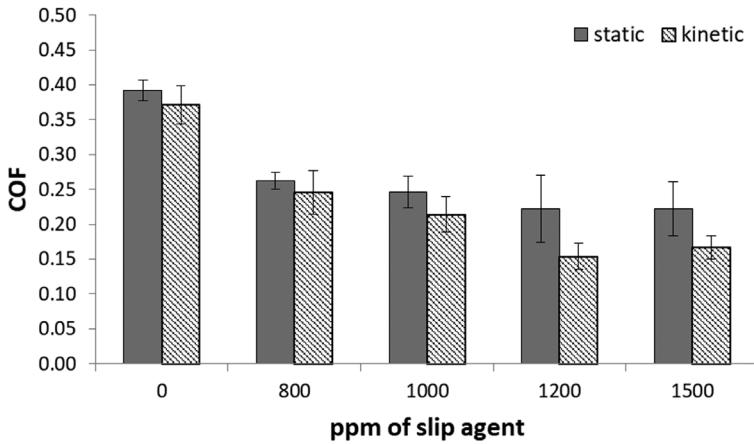


Figure 2: COF of LLDPE film at different contents of slip agent.

3.2 Tensile strength

The tensile strength of the LLDPE film at different contents of slip agent is shown in Figure 3. It can be seen that the tensile strength decreased as the contents of slip agent increased. The decrease of the tensile strength could be affected by the presence of microvoids in the matrix when slip agent exude to the surface and remaining slip agent in the bulk matrix. Obviously, both the microvoids and the remaining slip agent increased with increasing contents of the slip agent.¹² The tensile strength for samples at machine direction (MD) was found higher compared to those at the transverse direction (TD) with an average percentage difference of 35.10%. The effects of tensile strength at MD and TD direction can be explained by the orientation of LLDPE molecular chain during extrusion. In MD direction, the energy required to break and rupture the long molecular chain of LLDPE was greater when compared with the energy required to separate the space between LLDPE molecular chains in TD direction.

3.3 Elongation at Break

Figure 4 shows elongation at break of LLDPE film at different contents of slip agent. In general, the trend for elongation at break is inversely proportional to the tensile strength. It can be seen that elongation at break gradually increased as the content of slip agent increased from 0 ppm to 1,500 ppm. The slip agent is believed to act as a plasticiser within LLDPE chains. The slip agent fills the space between the polymer chains, increasing the separation between them, and causing a decrease in the polar forces of attraction.⁷ The elongation at break for samples at TD was found higher compared to those at MD direction with an average percentage

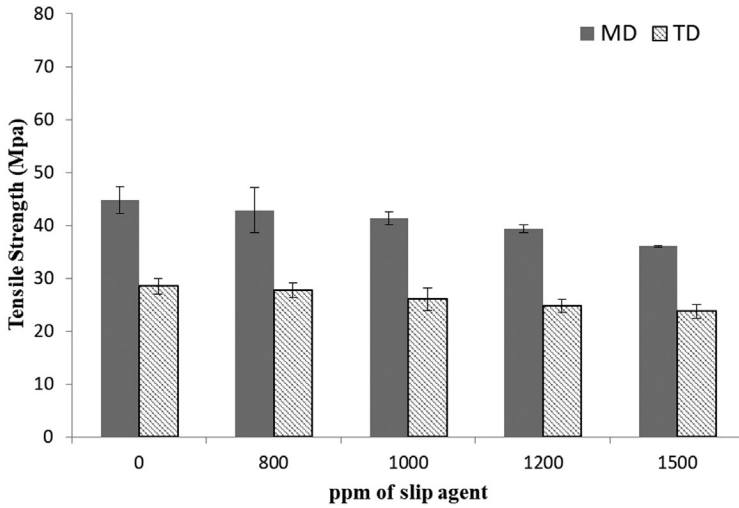


Figure 3: Tensile strength of LLDPE film at different contents of slip agent.

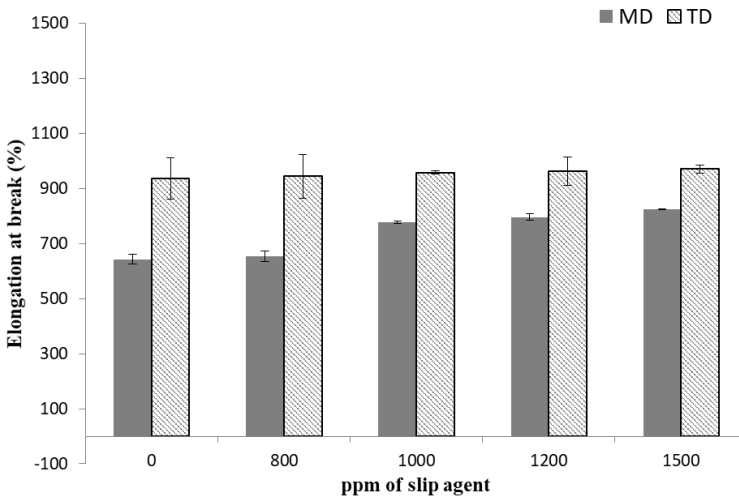


Figure 4: Tensile strength of LLDPE film at different contents of slip agent.

difference of 20.36%. The higher elongation at break at TD could be explained due to the flexibility of the molecular chains during deformation. During stretching, the spacing of LLDPE chains in TD increased such that increases the mobility of the molecular chains to slide and disentangle with each other. The elongation at break is determined after all the spacing and entanglement of LLDPE molecular chains is disrupted, whereas in MD the flexibility of the molecular chains is limited and the elongation at break is determined after all the molecular chain breakdown.

3.4 Young's Modulus

Figure 5 shows Young's modulus of LLDPE film at different contents of slip agent. As expected, Young's modulus decreased with increasing content of slip agent. The decreased of Young's modulus can again be explained due to the plasticisation effects bring about by the addition of slip agent. The slip agent penetrates between the polymer chains and decreased the intermolecular force resulting in lower polymer chain cohesion. Therefore, the stiffness was significantly decreased and the flexibility increased. It can also be seen that the Young's modulus for samples at TD was found higher compared to those at MD direction with average percentage difference of 15.34%. Higher values of Young's modulus corresponding to stiffer film where it requires higher force to elastically deform it. The lower Young's modulus at MD could be attributed to higher chain mobility which can be elastically deformed at lower force.

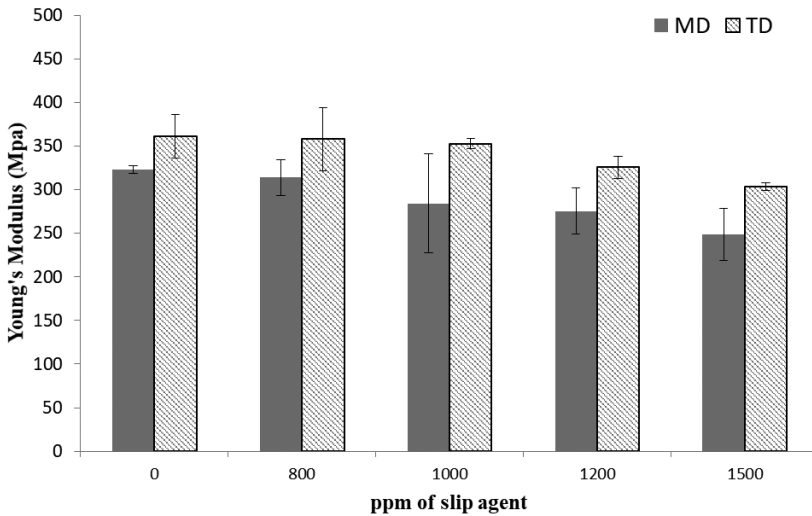


Figure 5: Young's modulus of LLDPE film at different contents of slip agent.

3.5 Gel Count

Gel count of LLDPE film at different contents of slip agent is shown in Figure 6. Generally, the number of gel count increased with increasing content of slip agent. The increase of gel count could be attributed to accumulation of small bits of higher molecular weight slip agent or contamination that reflect and transmit light differently from the material. Gels could also originate from several sources such as crosslinked material caused by overheating, residue or other organic or inorganic contamination.

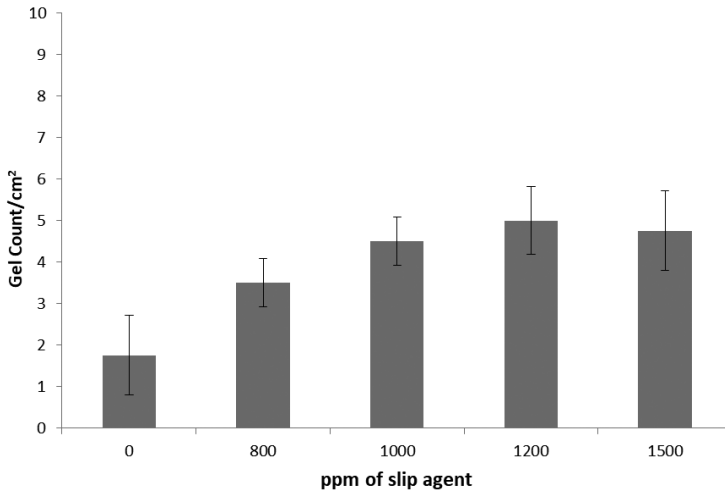


Figure 6: Gel count of LLDPE film at different contents of slip agent.

4. CONCLUSION

It was found that COF decreased with increase in content of slip agent which might be due to increased amides migration from the bulk matrix to the surface. Static COF had the highest value compared to kinetic COF. Tensile strength and Young's modulus was also found to decrease as the content of slip agent increased. The decrease in tensile strength and Young's modulus was believed to be due to the presence of the microvoids in the matrix after the slip agent exude to the surface and the remaining slip agent in the bulk matrix. As expected, elongation at break gradually increased as the content of slip agent increased. Addition of slip agent increased flexibility of the molecular chains during deformation. It was also found that the gel count increased with increase in content of slip agent such that could be explained due to small bits of higher molecular weight material or contamination in the materials.

5. ACKNOWLEDGEMENTS

This work is a research collaboration between School of Materials and Mineral Resources, Universiti Sains Malaysia and Product Technical Support, Innovation and Technology Department, Petronas Chemicals Polyethylene Sdn. Bhd. The authors would like to thank Universiti Sains Malaysia and Innovation & Technolgy, Petronas Chemicals Group for providing the materials and additives, research facilities and advices.

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