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EFFECT OF PROCESSING PARAMETERS ON MECHANICAL PROPERTIES OF LINEAR LOW-DENSITY POLYETHYLENE FILM

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ABSTRACT

Optimization of extrusion conditions is critical to the production of polyethylene films with good mechanical integrity. Yet past studies on the mechanical properties of polyethylene films have neglected the significant effect of critical extrusion conditions. Much of the research into the mechanical properties of polyethylenes, have been limited to the effect of conventional processing parameters such as temperature and pressure. The present study investigates the effects of blow-up ratio (BUR), die gap and output rate on mechanical properties of blown Linear Low-Density Polyethylene (LLDPE) films. The mechanical properties examined were impact strength, tear strength and tensile modulus. It was observed that there was an increase in impact strength, while tensile modulus decreased with increasing BUR. The increase in impact strength was attributed to film orientation in the transverse direction which improved with increasing BUR. In contrast, the observed decrease in tensile modulus was due to poor film orientation in the machine direction which was more pronounced with increasing BUR. At the narrowest die gap (1.27mm) and lowest BUR (2.0), the transverse direction (TD) tear strength showed a decrease at high output rates, but increased sharply at high output rates for all the resins. However, at both the low and high output rates, no dependence of the transverse direction (TD) tear strength on the intermediate die gap (2.03mm) was observed. The results show that the extrusion parameters studied are critical factors that determine film orientation and ultimate mechanical properties and, should be carefully controlled when extruding films from Linear Low-Density Polyethylene (LLDPE) resin.

Keywords: Polyethylene film, blow-up ratio, die gap, output rate

INTRODUCTION

In many of today's demanding packaging applications, high strength polymerfilms are essential. It is, therefore, necessary to determine optimum processing conditions in order to reap the full benefits of thesepolymers. The mechanical properties of all polyethylene films are highly dependent on extrusion conditions (Bisco, 2005). This is especially true for Linear-Low Density Polyethylene, in which the absence of long chain branching causes polymer chains to orient in the machine direction. Branch length is controlled by the type of comonomer used in the manufacture of polyethylene (Tavman, 2004). Butenecomonomerpolyethylenes have two carbon length branches; hexenecomonomer-polyethylene have four, and octenecomonomer polyethylene have six. Linear-Low Density Polyethylenes also have a relatively narrow molecular-weight distributions and are higher in viscosity at a given shear rate in comparison with traditional Low Density Polyethylene. These differences necessitate higher extruder power, backpressure, and melt temperature during the extrusion of Linear-Low Density Polyethylene. Much of the research into the mechanical properties of polyethylenes have been concerned with the effect of conventional processing parameters such as temperature and pressure on these properties, (Kunori, 2005). Although, Piggot, (2000), showed long ago that extrusion conditions could have profound effect on mechanical properties of polyolefins, studies have neglected the significant effect of critical extrusion conditions. Notable exceptions to the findings of Piggot are the studies of Lopez-Abdel et al, (2001)andMalti-Mahapatra et al, (2002). However, the later concerns the effect of repeated processing and re-processing on the mechanical properties of polyolefins and does not relate strongly to the processing parameters studied in the work presented here.Film producers who routinely extrude Linear Low-Density Polyethylenes often must modify the extrusion conditions, in order to produce films with good mechanical properties. Melt fracture, or sharkskin, can be a problem at high die shear rates. This can be eliminated by raising extrusion and die temperatures, increasing the die opening to reduce shear or using polymer processing aids, (Privalko, 2006).Blow-up ratio (BUR), is the ratio of the film bubble diameter to the die diameter, and it is critical in the processing of Linear Low-Density Polyethylenes. Low blow-up ratios impart orientation in the machine direction, often resulting in decrease in a film's physical properties, especially tear strength (Farrisey, 2005).The purpose of this study is to investigate the effects of BUR, die gap, and output rate on the mechanical properties of LLDPE films made with both hexene and octenecomonomers. Key film properties investigated were impact strength, tear strength and tensile modulus.

MATERIALS AND METHOD

Materials

LDPE resins and equipment for this study were provided by Cee-plast Ind. Nig Ltd, Aba, Nigeria. The study evaluated four LLDPE resins made with Conventional Octene (co) comonomer, Ultra-Low Density Octene (ULDO) comonomers, High-Strength Hexene (HSH), and Ultra-Low Density Hexene (ULDH) comonomer. Two key properties of the resins are presented in Table 1.

Table 1.Properties of polyethylene resins

Resin	*Melt flow index (dg/min)*	*Density (g/cm^3)*
Conventional Octene	1.0	0.92
Ultra-Low Density Octene	1.0	0.912
High-Strength Hexene	0.85	0.917
Ultra-Low Density Hexene	0.85	0.910

Sample Preparation

Five samples of LLDPE films (normally 0.038mm) were produced on extrusion blown-film line in Cee-plast Ind. Nig Ltd, Aba Nigeria, from each of the four LLDPE resins. The temperature in all three zones of the extruder and the die exit was set at 170^{0}C, and the screw speed was set at 80rpm. To facilitate film handling and testing, talc anti-block was added at 2000rpm to the inside and outside film layers. Three different die gaps (1.27, 2.03 and 2.53) were used. The extrusion line has an 8 – inch (20.32cm) die and employs internal bubble cooling system. Blow-up ratios of 2.0, 4.0 and 6.0 were used in this study. Two different output rates of 250 Ib/hr for the low output setting, and 350 Ib/hr for the high output setting were also used.

Impact Testing

Impact test specimens were prepared and tested at room temperature on Dart impact testing machine with a 26 – inch dart height according to ASTM D 1709 method A. Testing was done at room temperature. The mean value of five specimens of each resin sample was taken. The results are presented in Fig. 1.

Tear Testing

Tear tests on the resin samples were conducted at room temperature according to ASTM D1922 using a Ceast tear tester. The mean value of five specimens of each resins sample was taken. The results are presented in Tables 1 and 2.

Tensile Testing

Tensile specimens were tested on an Instron testing machine according to ASTM D 683 test procedure. Testing was done at room temperature by using a crosshead speed of 50mm/min and load range of 0 – 500N. The mean value of six specimens of each resin sample was taken. The results are presented in Figure 2 and Figure 3.

RESULTS AND DISCUSSION

Figure 1 shows the effect of BUR on dart impact strength for all the four resin samples studied at output rate of 350 Ib/hr. The results show that, dart impact strength increased with increase in BUR for all resin samples. Predictably, the Conventional Octene (CO) resin, which has the highest density, produced films with the lowest Dart impact strength of all the resin samples tested. Dart impact strength for all four resin samples did not show any appreciable change with change in die gap. Ultra-Low Density Hexene (ULDH) resin, however, showed poorer impact strength at the narrowest (1.27mm) die gap and under conditions of high output. This is attributed to higher shear rates in the polymer melt, but the film did not show evidence of melt fracture at these conditions.

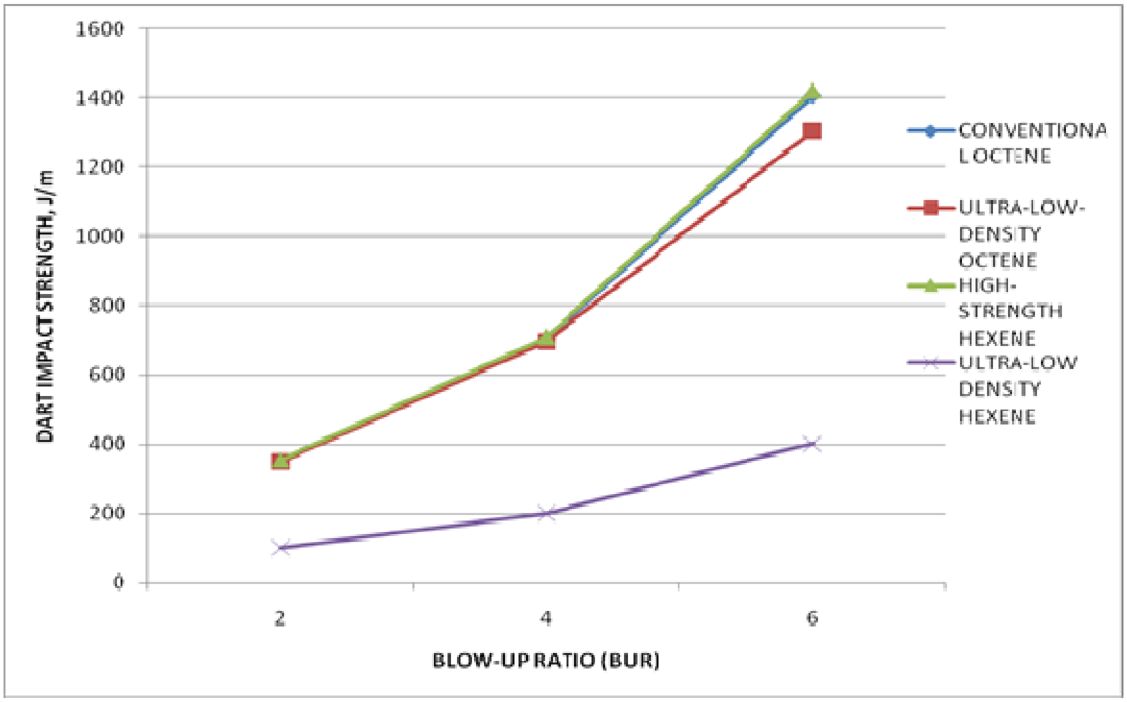

Figure 1.Effect of Blow-up ratio (BUR) on Dart impact strength at output rate of 350 Ib/hr

The effect of resin on the transverse direction (TD) tear strength is presented in Table 2. The results show that there are no significant differences in the TD tear strength for all the resins studied. These results are comparable to similar results on correlation between High- Density Polyethylene (HDPE) and Low- Density Polyethylene (LDPE) on tear strength earlier reported by Crank (2004). Table 3 shows that at the narrowest die gap (1.27mm) and lowest BUR (2.0), the transverse direction (TD) tear strength showed a decrease at high output levels, but increased sharply at high output levels for all the resins. However, at both the low and high output levels, no dependence of the transverse direction (TD) tear strength on the intermediate die gap (2.03mm) was observed.

Table 2.Effect of resin on TD Tear strength

Resin	TD tear Strength (N/m^2)
Conventional Octene	865
Ultra-Low Density Octene	864
High-Strength Hexene	862
Ultra-Low Density Hexene	863

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Correlation between modulus and some of the processing parameters studied are shown in Figure 2 and Table 3.

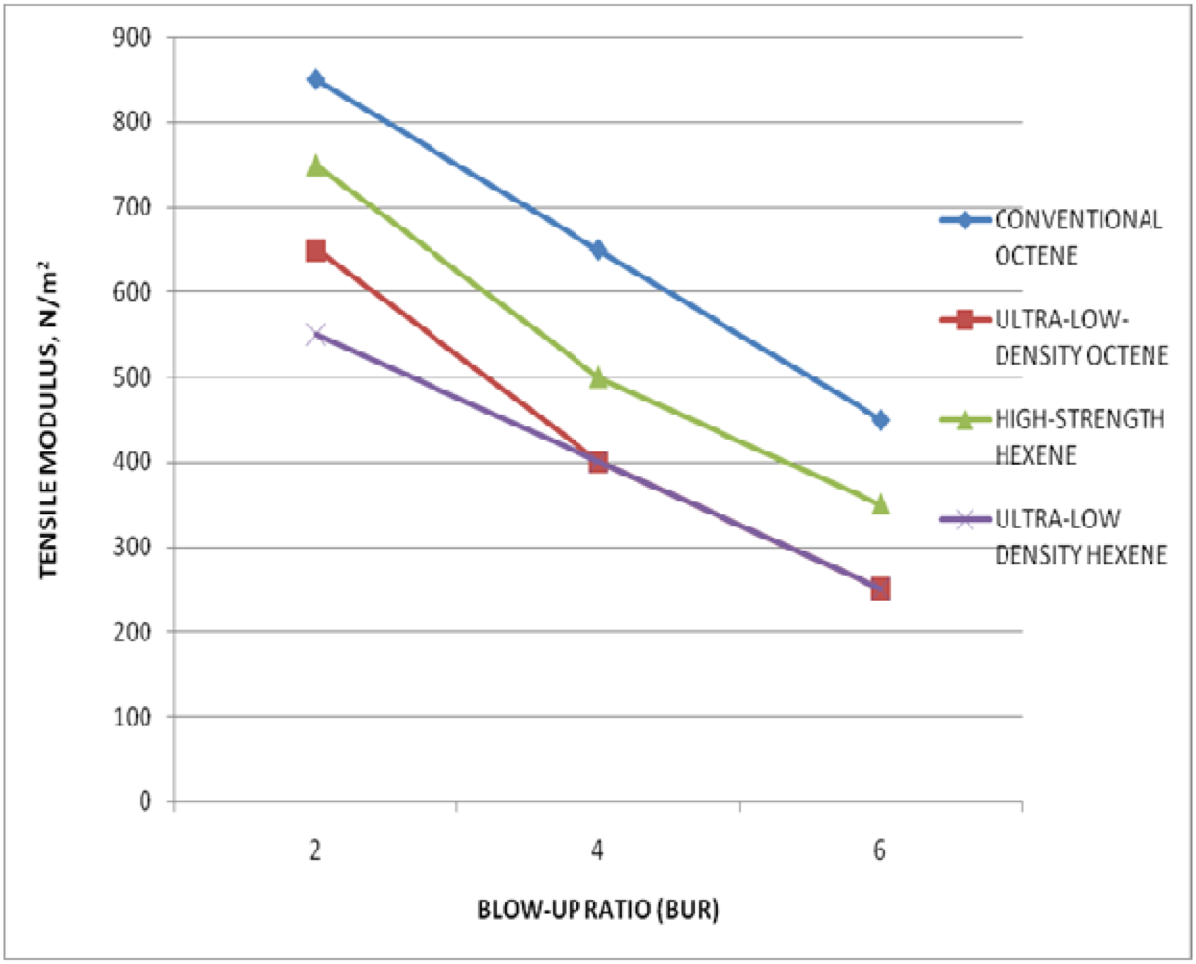

Figure 2.Effect of Blow-up ratio on tensile modulus

Table 3.Effect of Output rate on Transverse Direction (TD) Tear strength

Resin	*Die gap (mm)*	*Blow-up ratio (BUR)*	*TD Tear strength (N/m^2) at:*	
			350 Ib/hr Output	*250 Ib/hr Output*
Conventional Octene	1.27	2.0	644.1	850.5
	2.03	2.0	645.0	645.1
	2.53	2.0	645.4	645.0
Ultra-Low Density Octene	1.27	2.0	745.0	980.5
	2.03	2.0	745.3	745.0
	2.53	2.0	746.0	745.0
High-Strength Hexene	1.27	2.0	955.0	1235.0
	2.03	2.0	955.3	955.5
	2.53	2.0	956.0	956.2
Ultra-Low Density Hexene	1.27	2.0	1096.5	1885.3
	2.03	2.0	1096.9	1096.0
	2.53	2.0	1097.3	1097.0

The results show that modulus decreased with increasing BUR. All the resins studied produced different modulus values. This may be due to differences in their densities. Fig. 2 also shows that the resin made with Conventional Octene (CO) comonomer with a density of 0.92g/cm^3, produced the highest modulus value, while the Ultra-Low Density Hexene (ULDH) resin with the lowest density of 0.910g/cm^3 had the lowest modulus value. Correlation between modulus and die gap did not follow any regular pattern as the intermediate die gap of 2.03mm produced the highest modulus values. In contrast, modulus increased with increase in blow-up ratio (BUR). This effect has been observed in previous studies, (Yamaguchi *et al*, 2001); and it is due to decrease in film orientation with increasing BUR.

CONCLUSION

Processing conditions have a significant effect on mechanical properties of polyolefin films. Blow-up ratio (BUR) and die gap are critical factors that determine film orientation and hence, ultimate mechanical properties. These effects, which are independent of the resin comonomer, should be carefully controlled when extruding films from Linear-Low Density Polyethylene (LLDPE) resin. Films with a wide range of mechanical properties can be produced using the same resin and same extrusion line by varying the extrusion conditions.

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