Influence of the extruder screw design on the optical, physical, and thermal properties of polyethylene compounds

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ABSTRACT

In this work, the influence of extruder screw design such as aspect ratio (L/D) and the mixing sections on the properties of extruded medium density polyethylene (MDPE) compound was investigated. For this purpose, three different types of extruders were used and the optical, physical, and thermal properties of the produced compounds were evaluated. The design of the extruder screw can affect the shear rate, residence time and temperature profile of the polymer melt. Finally, the results of experimental tests showed that the processing and final properties such as thermal resistance, oxidative decomposition, degree of crystallinity, L.a.b color parameters of MDPE compounds were significantly dependent on the type of extruder geometry.

Keywords: Extruder Screw Design, Medium Density Polyethylene Compound, L.a.b, Thermal Properties, OIT.

1. INTRODUCTION

The properties of polymer compounds are significantly influenced by the design of the extruder screw. The tasks of the extruder screw include melting, mixing the polymer and additives, as well as transferring the polymer compound throughout the extruder barrel. The screw design affects the shear rate, residence time, and temperature profile of the polymer melt, all of which affect the final properties of the polymer compound. One of the important parameters in screw design is the compression ratio, which refers to the ratio of the channel depth in the feed zone to the channel depth in the meter zone. A higher compression ratio can increase the shear rate and mixing intensity, thereby improving the dispersion of additives and reducing the agglomeration of filler particles. Nevertheless, excessively high compression ratios can also lead to overheating and thermal degradation of the polymer. Furthermore, the occurrence of backflow can result in temperature fluctuations in the polymer melt and potentially change the characteristics and color of the polymer compound. This, in turn, can reduce the performance and durability of the final product. Another important parameter is the pitch of the screw flights, and since a shallow pitch can increase the residence time, it affects the polymer compound properties. Conversely, a deep pitch can increase the conveying capacity of the screw and minimize the occurrence of backflow. Therefore, in order to optimize the production rate and the quality of the produced polymer compound, factors such as the ratio of length to diameter, the number and shape of the mixing elements, the degree of taper in the screw profile must be correctly considered in the screw design (1-3). The main objective of the current research is to evaluate effects of extruder screw design such as aspect ratio (L/D) and the mixing sections on the properties of extruded medium density polyethylene (MDPE) compound. For this purpose, three different types of extruders were used and the optical, physical, and thermal properties of the produced compounds were evaluated.

2. Experimental:

2.1. Material

Medium Density Polyethylene (MDPE) purchased from Tabriz Petrochemical. The characteristics of commercial grade Medium Density Polyethylene employed in this research are illustrated in Table1.

Table 1. The specifications of the polymer used in this research

Polymer	Grade	Density (g/cm^3)	MFI(g/10min at 190 °C/2.16 kg)
MDPE	3840	0.938	4

2.2. Methods

The MDPE compound samples were prepared by melt mixing with the addition of 3% pigment masterbatch and 3% $Caco_3$ filler. The samples prepared with single screw extruders are summarized in Table 2. Since the specifications of the length and diameter of the extruders are different, the mixing duration of the compounds was variable.

Table 2: Sample codes and characteristics of extruders for produced polyethylene compound in this research.

Extruder Number	Mixing Section	L/D Ratio	Sample Code
1		22	EX1
2		23	EX2
3		25	EX3

Differential Scanning Calorimeter (DSC) and oxidation induction time (OIT) tests of the samples were performed using DSC-OIT-400 SANAF.
According to the International Commission on Illumination (CIE), the color of polymer samples can be evaluated through L*a*b* coordinates. In this system, L* is the color lightness (L* = 0 for black and L* = 100 for white), a* is the green (-)/red (+) axis, and b* is the blue (-)/yellow (+) axis. The color of polyethylene compounds was determined by optical spectroscopy using portable spectrophotometer NR145. The total color difference parameter (ΔE) was calculated according to the formulation (1):

$$\Delta E= [(\Delta L^*)^2+ (\Delta a^*)^2+ (\Delta b^*)^2]^{0.5} \qquad (1)$$

3. Results:

3.1. Physical properties:

Figure 1 illustrates the density and MFI values of polymer compounds extruded using the three different extruders with different screw mixing sections.

Significantly, the density value for the MDPE compound produced with extruder No. 3 (EX3) was lower than other samples. This was probably due to the large number of air bubbles which increased the volume of the extrudate. It can also be seen that the MFI value for sample EX3 is higher than other samples. The increase in the melt flow index in the function of the length-to-diameter ratio is caused by the accelerating degradation which can contribute to a decrease in the performance and durability of the final product.

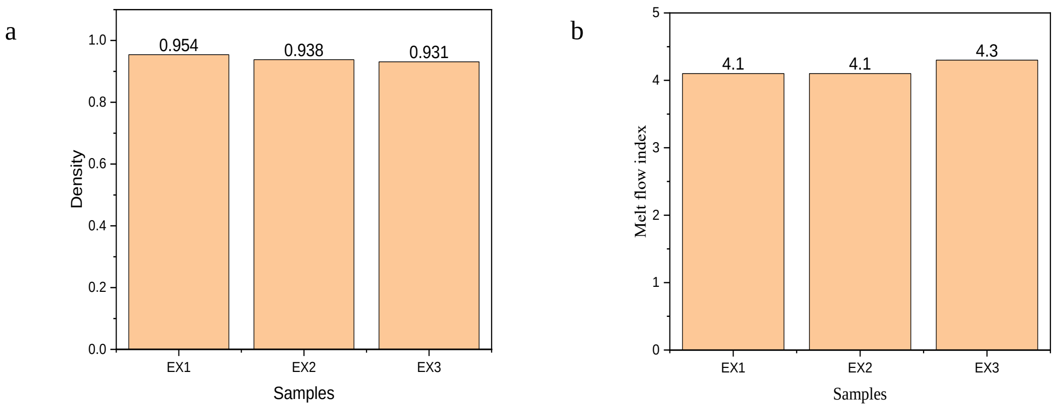

Figure 1: a) Density and b) MFI values of extrudate MDPE compound using different screw mixing section.

3.2. Thermal properties:

The DSC and OIT analysis are used to provide insights into the behavior of polymer compound samples during heating and cooling processes, which can help optimize processing conditions for desired compound properties and supporting the assessment of long-term performance and service life. The thermal properties of polymer compounds extruded using the three different extruders with different screw mixing sections are summarized in Table 3. The shear rate has a significant influence on the crystallinity of polyethylene. Higher shear rates generally result in lower crystallinity due to disrupted chain alignment and increased chain scission.

Table3: OIT value and Thermal properties received in a DSC measurement.

Sample	OIT	X_c	T_C	T_m
EX1	42.65	86%	112	123
EX2	31.68	80%	112	124
EX3	27.92	90%	111	121

3.3. Color:

The obtained results of the measurements of the L*, a*, and b* parameters variability of the extrudate produced using the screw mixing section tested, depending on different screw types are shown in Table 4. It should be noted that the b parameter of the extrudate compound produced by using the third mixing section (EX3) was slightly increased and the color leans toward darker and yellow. It has been observed that with increasing ΔE associated with degradation of material was observed for the third mixing section, for which the highest absorbance ratio values related to the degradation effects.

Table 4: Comparison of L*, a*, and b* data for extrudate MDPE compound using different screw mixing section.

Sample	Δa	Δb	ΔL	ΔE
EX1:EX2	0.010	0.351	-0.620	0.712
EX2:EX3	0.113	-0.391	2.465	2.499
EX1:EX3	0.125	-0.509	1.556	1.642

4. Conclusion:

The design of the extruder screw, including the aspect ratio (L/D) and the mixing sections, significantly affected the optical, physical, and thermal properties of polyethylene compounds. The shear rate, residence time, and temperature profile of the polymer melt were influenced by the extruder screw design. The type of extruder geometry used in the processing of medium density polyethylene (MDPE) compounds had a significant impact on the thermal resistance, oxidative decomposition, degree of crystallinity, and color parameters (L.a.b) of the final product. The length-to-diameter ratio of the extruder screw affected the density and melt flow index (MFI) of the extrudate. A larger number of air bubbles in the extrudate can lead to lower density values. The increase in the length-to-diameter ratio can accelerate degradation, resulting in higher MFI of polymer compound and potentially decreasing the performance and durability of the final product.

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