Article

Influence of the Main Blown Film Extrusion Process Parameters on the Mechanical Properties of a High-Density Polyethylene Hexene Copolymer and Linear Low-Density Polyethylene Butene Copolymer Blend Used for Plastic Bags

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Featured Application: This work is of particular interest in the design of products widely used in daily life, such as HDPE and LLDPE blend plastic bags. The aim of this study is to analyze how the main process parameters (BUR, TUR, and TR) affect the mechanical properties of this type of product, helping designers to adapt the production to customers' new requirements while maintaining the product properties. All the samples were manufactured on an industrial scale. The results are beneficial so that the highest tensile and impact properties can be obtained through minimal changes in the already mentioned process parameters, thus also reducing the amount of waste due to products manufactured outside the specification limits.

Abstract: Polyethylene plastic bags manufactured via blown film extrusion have different quality specifications depending on their intended use. It is known that the mechanical properties of a film depend on the process parameters established, but little is known concerning how they affect one another, even more so due to the variety of polyethylene materials and processing techniques. This study focuses on establishing a proper correspondence of important mechanical properties like the dart impact, tensile strength at break, and elongation at break with commonly used process parameters like the blow-up ratio, take-up ratio, thickness reduction, and neck height, for a high-density polyethylene hexene copolymer and a linear low-density polyethylene butene copolymer blend film. Because this polyethylene mixture is an anisotropic material, interesting R^2 values equal to or higher than 0.90 were found: a BUR with elongation at break and tensile strength at break in the MD and TD, a TUR with elongation at break in the MD and tensile strength at break in the MD and TD, and a TR with elongation at break and tensile strength at break in the MD. Also, a relationship between the dart impact and both the neck height and thickness were found.

Keywords: blown film extrusion; HDPE; LLDPE; mechanical properties; process parameters; plastic film

Citation: Cuesta, F.; Camacho, A.; Rubio, E. Influence of the Main Blown Film Extrusion Process Parameters on the Mechanical Properties of a High-Density Polyethylene Hexene Copolymer and Linear Low-Density Polyethylene Butene Copolymer Blend Used for Plastic Bags. *Appl. Sci.* **2023**, *13*, x. https://doi.org/10.3390/xxxxx

Academic Editor(s): Name

Received: 27 January 2023
Revised: 27 October 2023
Accepted: 3 November 2023
Published: date

1. Introduction

Polyethylene (PE) is considered one of the most important thermoplastics used today [1], mainly due to its low price, high durability, chemical inertia, and easy conversion into various forms and sizes of plastic products. This semi-crystalline polyolefin is widely used to manufacture plastic films [2], bags, and other agricultural products [3], produced via blown film extrusion. Both HDPE (high-density polyethylene) and LLDPE (linear low-density polyethylene) are largely used today and exhibit great mechanical performance, even with low gauge [4]. Due to their growing popularity, many studies have been made to improve their manufacturing process, particularly in the extrusion operation, with the goal of enhancing their mechanical properties [5]. However, there is still the need for a better understanding of the effects that the process conditions have on the molecular orientation and therefore on the film's mechanical properties. Because polyethylene is considered to be the dominant packaging material among polymers, it is very important to consider in detail which parameters and properties need to be studied and correlated in order to improve its use [6].

There are few studies that have analyzed the effect of process conditions such as the neck height (NH), blow-up ratio (BUR), take-up ratio (TUR), and thickness reduction (TR), on the mechanical properties of HDPE films. Godshall et al. [7] reported how the gauge reduction is related to the dart impact strength, and found that for HDPE with a high molecular weight, the dart impact strength increases, while for HDPE with a lower molecular weight, it decreases. Auksornkul et al. [8] studied the effect of the BUR on elongation mechanical properties for different LLDPE resins and found that, within the range from 1.7 to 2.8, the machine-direction tensile strength decreased and the transverse-direction tensile strength increased. Furthermore, Mariam Al-Ali AlMa'adeed and Igor Krupa [9] presented a range of NH values to obtain optimal dart impact strength. These studies presented results that relate some process parameters with mechanical properties in HDPE films or in LLDPE films. However, there are no studies that analyze all of the above-mentioned process parameters to establish correlations with mechanical properties on an industrial scale using an HDPE and LLDPE blend.

The purpose of this study is to analyze how different variations of the main process parameters of blown film extrusion (NH, BUR, TUR, and TR) affect the mechanical properties of the final product, such as the dart impact strength and tensile elongation, in the machine direction (MD) and transverse direction (TD) of HDPE and LLDPE blend films on an industrial scale. The correlations found between the process parameters and the mechanical properties are presented.

2. Materials and Methods

2.1. Materials

The polyethylene film samples were manufactured with a mixture of 75% high-density polyethylene hexene copolymer (HDPE-C6) and 25% linear low-density polyethylene butene copolymer (LLDPE-C4). This proportion was used because it is the one the factory found to be more suitable for their market to maintain a balance between the cost of both materials and the quality of the final product. The properties of the two thermoplastics are shown in Table 1, according to the information reported in the technical data sheet of Chevron Phillips Chemical Company LLC (The Woodlands, TX, USA) for HDPE-C6 [10] (which is a bimodal high-molecular-weight HDPE) and of ExxonMobil (Houston, TX, USA) for LLDPE-C4 [11], both designed for the blown film process.

Table 1. Polymers' properties.

Property	HDPE-C6 [1]	LLDPE-C4 [2]
Melt Index at 190 °C—2.16 kg (g/10 min)	0.06	2.00
Melt Index at 190 °C—21.6 kg (g/10 min)	9.50	-
Density (g/cm^3)	0.950	0.918
Dart Impact (g)	260	60
Tensile Elongation at Break MD (%)	260	620
Tensile Elongation at Break TD (%)	570	770
Elmendorf Tear Strength MD (g)	15	110
Elmendorf Tear Strength TD (g)	450	390
Antiblock (ppm)	0	3500
Slip (ppm)	0	1500

[1] HDPE-C6 at 12.5 μm being Marlex® TRB-115 from Chevron Phillips Chemical Company LLC; [2] LLDPE-C4 at 25.4 μm being ExxonMobil™ LLDPE LL 1002xBU from ExxonMobil.

2.2. Manufacturing Samples, Equipment, and Bubble Configuration

The film samples were taken based on the specifications of the products manufactured in the factory. The different samples varied in width (432 mm to 990 mm) and thickness (9.5 μm to 56.6 μm). These particular dimensional variations were used because of the technical capacity of the manufacturing process; they also reflect the variations in the factory's products. To ensure that the process was stable, the samples were taken at around 200 kg (approximately 3 h) after the film was calibrated.

To manufacture the samples, only one mono-layer extrusion machine was used. The characteristics of the extruder are the following: Brand Carnevalli (Guarulhos, Brazil), 60 mm diameter screw with 1.5 m length (25:1 ratio), 125 mm diameter head, 1 mm die gap, and 150 mm diameter pull roller. The process temperatures were configured in the three screw-barrel zones (considering a variation of ±7 °C) as follows: zone 1 at 180 °C, zone 2 at 185 °C, and zone 3 at 190 °C; and the die temperature at 195 °C [12].

The configuration used was the configuration of "high stalk", because the main proportion of the material is 75% HDPE, a linear polymer. Figure 1 shows the difference between these two common configurations: "in the pocket" and "high stalk". Typically, to manufacture blown films of LDPE and LLDPE, the "in the pocket" configuration is used because it is a branched polymer, and for HDPE, the "high-stalk" configuration is used, within a certain range of values of neck height (normally from 7 to 9 times the die diameter) [9].

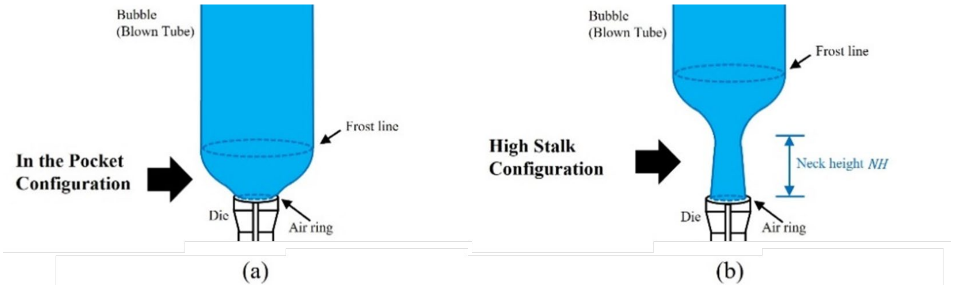

Figure 1. Differences between two configurations: (**a**) in the pocket and (**b**) high stalk.

2.3. Calculation of Process Parameters

To calculate the process parameters, different variables need to be taken into consideration. The changes in these variables occur due to the desired characteristics of the product, which have different combinations of width (W) and thickness (e). Within these combinations, the neck height (NH) was also varied. These variables are seen in Figure 2.

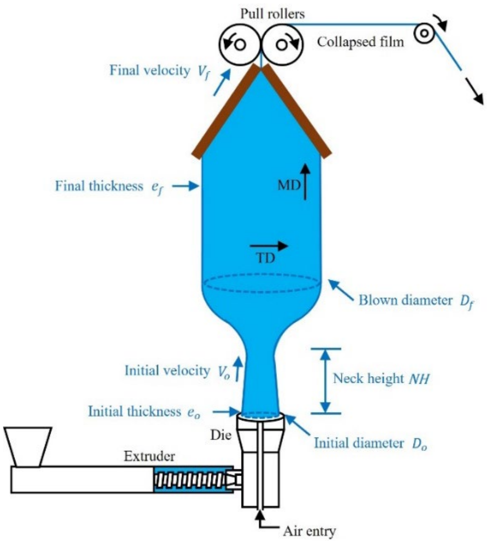

Figure 2. Diagram of the blown film extrusion process considering its parts and process variables.

The process parameters that where calculated were the following:

- The blow-up ratio (BUR), which is calculated according to Equation (1), where D_f is the ratio of the blown diameter, which is also $2/\pi$ (around 0.637) times the width of the collapsed film, and D_o is the initial diameter [8].

$$BUR = \frac{D_f}{D_o} \quad (1)$$

$$BUR = \frac{2W}{\pi D_o} \quad (2)$$

- The take-up ratio (TUR), defined in Equation (3), is expressed as a ratio between the speed of the film above the height of the freezing line (given with the pulling rollers) and the melting speed at the exit of the die [9].

$$TUR = \frac{V_f}{V_o} \quad (3)$$

In the current study, the melting speed was measured by calculating the amount of time in which a dot that is just leaving the die exit reaches a given distance (in this particular case, 24 inches), thus calculating the initial linear speed of the material leaving the die. The final speed was calculated using the angular speed of the pulling rollers, turned into linear speed.

Nevertheless, using the variables from this study shown in Figure 3, the TUR could also be calculated using the mass conservation principle [13]:

$$\rho_f A_f v_f = \rho_o A_o v_o \quad (4)$$

$$TUR = \frac{\rho_o\left(R_o^2 - r_o^2\right)}{\rho_f\left(R_f^2 - r_f^2\right)} \quad (5)$$

$$TUR = \frac{\rho_o(e_o)(D_o - e_o)}{\rho_f(e_f)(D_f - e_f)} \quad (6)$$

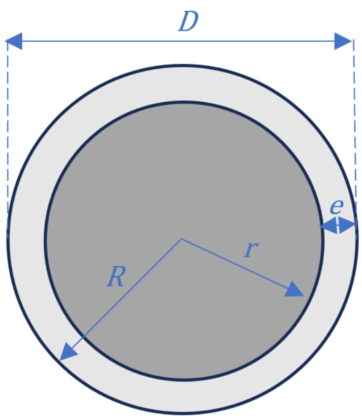

Figure 3. Scheme of two concentric circles and their variables representing the relationship of diameters and thickness, both in the die exit and above the freeze line.

- The thickness reduction (TR), shown in Equation (7) is the ratio between the opening of the nozzle lips (or die gap) and the final thickness (e) of the film [14], or the ratio between gauges.

$$TR = \frac{e_f}{e_o} \quad (7)$$

- The neck height (NH_{DD}) is calculated according to Equation (8), where the value, in millimeters, is divided by D_o. The ratio between the neck height and the die diameter used in the process is due to the different types of dies that are available [15].

$$NH_{DD} = \frac{NH_{mm}}{D_o} \tag{8}$$

- Finally, it is also important to consider the forming ratio (FR). While it is not an independent variable, it relates the TUR with the BUR to determine the grade of symmetry between these two parameters, because the BUR mainly impacts the transverse-direction properties and the TUR mainly impacts the machine-direction properties [13].

$$FR = \frac{TUR}{BUR} \tag{9}$$

The experimental design can be described as the following: the initial diameter, the initial thickness (or die gap), and the initial velocity are kept constant; the blown diameter, the final thickness, and the final velocity are changed with the purpose of obtaining different product sample groups with different BURs, TURs, and TRs; and finally, within those product sample groups (which have the same width and thickness) three variations in the neck height are made: tall (between 140 and 160 cm), medium (between 110 and 125 cm), and small (between 70 and 100 cm).

2.4. Determination of Mechanical Properties

To understand the variations in the final properties of the films obtained through blown film extrusion, it is vitally important to know how the characteristics of the polymer, the equipment used, and the processing variables affect the morphology, crystallinity, and orientation developed by the films [8]. In fact, the orientation of polymers improves many of their properties, particularly mechanical, impact, barrier, and optical [16]. Among the most important blown film properties are those related to elongation and impact [17].

2.4.1. Elongation at Break

Elongation at break (ε) is one of the most widely used properties in the industry to measure the quality of a film [18]. This property, together with the modulus of elasticity, or Young's modulus (E), and the value of the tensile strength at break (which is the value of the strength at which the sample breaks), is determined based on the ASTM D882 standard in a universal test equipment [16], in this case, Shimadzu AGS-X (Kyoto, Japan) of 100 N. The most updated version is ASTM D882-18 [19]. The method of this ASTM standard generally covers the determination of the tensile properties of plastics in the form of thin sheets (less than 1 mm). Specific stretching speeds and dimensions are defined based on the thickness of the sample. The elongation at break is calculated by dividing the extension at the time of sample breakage by the initial gauge length of the sample [18], as shown in Equation (10).

$$\%\varepsilon = \frac{\varepsilon_f}{\varepsilon_o} \tag{10}$$

2.4.2. Dart Impact Strength

Dart impact strength (ID) illustrates the toughness of films with regard to the resistance in applications given to films in different markets. In commercial production, polyethylene films are evaluated according to this parameter [20]. The method to determine the impact resistance of plastic films via the means of a dart in free fall is ASTM D1709, and covers the determination of the energy that causes a plastic film to fail, under certain specific conditions of a dart in free fall. The energy required for failure is expressed as the mass of the dart at a specific height, resulting in a 50% failure of the test specimen [21]. This property is calculated with the staircase testing technique, using Equation (11).

$$W_F = W_o + \left[\Delta W\left(\frac{A}{N} - \frac{1}{2}\right)\right] \quad (11)$$

where W_F is the weight in grams of the final value of the calculated dart impact, W_o is the value of the lowest weight in grams with which the dart broke the tempered film, ΔW is the differential of the weight in grams that is used to increase or decrease the weight of the dart, N is the number of breaks (which must be 10 or greater), and A is the value of the total sum of the multiplication of the number of breaks at each weight with the corresponding integer starting with 0 for the lowest break value, 1 for the next, then 2, 3, etc. [19].

2.5. Correlation between Process Parameters and Mechanical Properties

Finally, with the recorded data from the process parameters and the mechanical properties, correlations can be determined using the correlation coefficient, R^2, which is the proportion of the variation in the dependent variable that is predictable from the independent variable. This will be determined using different possible functions, such as polynomial, exponential, and potential. The correlation value ranges from 0 (meaning there is no correlation between the two variables) to 1 (meaning there is a total correlation represented by the mathematical model) [22].

3. Results

3.1. Process Parameters

In order to observe how the process parameters take different values, 25 different tests were carried out, among which there were different variations in the width of the film and its thickness. Consequently, the parameters of the BUR (due to the variation in the width), TUR (due to the variation in the pulling roller speed required by the variation of thickness), and TR (due to the direct variation in the thickness) were also varied. The neck height values were also varied within these. Finally, the FR is also calculated as a control parameter. All results are shown in Table 2.

The tests were carried out in groups of three. This can be seen by observing that the TUR is constant in every three tests. The first three tests were carried out by trying to keep the width and thickness constant, varying only the neck height in three values. The same was performed with the next three, and so on until test 21. Tests 22 to 25 were performed independently.

The three NH variations shown in Table 2 for each test with a combination of width and thickness can be more easily observed up to number 21. The test with the lowest neck height is number three, while the one with the highest neck height is number four.

3.2. Mechanical Properties

The results of the mechanical properties from each variation made in the process parameters can be seen in Table 2.

By observing the results obtained from the dart impact tests, some correspondence can be noted. Table 2 shows that samples 1 and 2 have the greatest dart impact strength values. Furthermore, these results show that samples 1 and 2 have the highest TR and the lowest thickness. On the other hand, samples 19, 20, and 21 have the lowest dart impact strength (less than 99 g) of all the samples, whilst also having the highest film thickness (greater than 40 μm) and lowest TR (17.7 to 22.8). These results are consistent with a previous study by Godshall et al. [7], where it was established that thinner high-density polyethylene films had a greater dart impact and vice versa. In their study, they do not give an explanation of why this behavior occurs, but they clarify what happens with the material that had the lowest amount of high-molecular-weight material.

Table 2. Value of product and process parameters and mechanical properties per sample [1].

Sample	Product and process parameters							Mechanical properties						
	Width (cm)	Thickness (μm)	BUR	TUR	TR	NH_{DD}	FR	E in MD (N/mm²)	ε in MD (%)	F_{max} in MD (N)	E in TD (N/mm²)	ε in TD (%)	F_{max} in TD (N)	Dart Impact (g)
1	88.7	9.5	4.5	5.0	105.3	11.2	1.1	658.9	269.8	11.8	715.5	365.8	11.8	297.5
2	86.4	9.7	4.4	5.0	103.1	8.8	1.1	569.2	299.0	12.0	647.7	401.9	12.1	300.5
3	87.3	9.9	4.4	5.0	100.9	5.8	1.1	656.7	294.6	14.6	665.2	496.5	6.3	106.4
4	92.2	18.0	4.7	3.3	55.5	12.8	0.7	622.9	470.4	24.6	550.1	528.6	18.0	216.5
5	98.9	16.7	5.0	3.3	59.9	10.1	0.6	647.4	436.7	26.0	772.9	733.5	17.5	152.0
6	97.3	16.1	5.0	3.3	62.1	7.4	0.7	628.1	384.1	24.6	722.0	589.7	15.3	152.0
7	85.1	10.2	4.3	5.4	98.4	11.6	1.3	363.5	265.9	16.5	347.8	523.0	8.3	159.5
8	88.7	9.9	4.5	5.4	100.9	9.8	1.2	263.7	268.9	13.4	278.3	511.4	9.0	176.0
9	88.7	10.1	4.5	5.4	98.9	7.8	1.2	525.8	280.6	16.6	410.6	534.6	7.6	124.0
10	81.6	11.1	4.2	3.6	90.1	11.6	0.9	742.2	297.6	15.0	803.0	509.3	12.6	218.0
11	81.9	11.4	4.2	3.6	87.7	9.7	0.9	552.6	363.8	13.8	762.6	443.3	14.8	254.0
12	82.7	11.4	4.2	3.6	87.7	7.3	0.9	584.1	365.8	17.3	761.5	464.8	10.9	158.0
13	88.6	11.8	4.5	4.2	84.7	11.8	0.9	517.9	329.0	17.2	637.0	617.3	9.8	132.5
14	88.7	12.6	4.5	4.2	79.4	9.8	0.9	408.8	286.3	13.0	427.8	524.3	7.9	99.5
15	89.7	13.2	4.6	4.2	75.7	7.4	0.9	493.2	329.0	15.5	496.3	532.1	7.4	108.5
16	96.2	19.8	4.9	2.5	50.5	11.9	0.5	625.0	431.1	25.5	704.2	647.7	17.3	162.5
17	96.4	19.5	4.9	2.5	51.3	9.6	0.5	538.8	417.0	22.4	515.5	622.1	16.5	168.5
18	97.8	18.0	5.0	2.5	55.5	7.4	0.5	548.1	408.3	22.8	663.5	678.2	15.9	120.3
19	43.2	43.9	2.2	1.5	22.8	12.1	0.7	554.2	796.2	54.5	584.2	1146.4	47.1	80.4
20	46.4	52.1	2.4	1.5	19.2	10.1	0.7	543.3	796.5	57.0	682.5	1129.1	46.1	95.4
21	47.0	56.6	2.4	1.5	17.7	7.7	0.6	557.1	667.4	53.3	766.4	1063.7	36.9	90.1
22	97.8	22.5	5.0	3.1	44.4	11.2	0.6	379.2	367.9	26.6	384.0	454.9	11.2	230.0
23	87.0	10.0	4.4	5.1	99.9	11.2	1.2	416.2	270.8	12.8	555.7	391.9	7.1	198.5
24	84.9	13.1	4.3	4.5	76.3	9.7	1.0	617.7	340.8	20.4	682.4	481.6	11.2	186.5
25	89.5	13.4	4.6	4.5	74.6	7.0	1.0	670.2	348.5	21.1	604.5	502.3	9.2	128.0

[1] The length of the bars represents the amount of each value relative to all the values in the column.

Another phenomenon reported by Godshall [7] is the increase in dart impact strength by increasing the neck height (raising the height of the cooling line). This is also observed in those samples that have relatively constant thickness values (less than 0.5 μm within the same group). According to Table 2, the test groups with constant thickness values are samples 1 to 3, 7 to 9, and 10 to 12. In the three cases, the lowest value of neck height (less than eight) gives the lowest dart impact value. However, in these three cases, the second value is the one that has the greatest dart impact of the group, with NH_{DD} values between eight and eleven. These results are similar to those indicated by Mariam Al-Ali AlMa'adeed and Igor Krupa in the book *Polyolefin Compounds and Materials*, edited by them [9], where they indicate that the heights should be approximately between seven and nine.

4. Discussion

Through a dispersion matrix, the different degrees of correlation between all the variables analyzed were compared with regard to the process and product variables. Those correlations in which the highest R^2 value was found are those of parameters BUR, TUR, and TR, together with some of the mechanical performance results of the universal test equipment: ε MD and TD, and also F_{max} MD and TD. This could be based on what Simpson [23] found in his research on HDPE: that increasing the TUR also increases the amorphous orientation in the MD, and that increasing the BUR also increases the amorphous orientation in the TD. No correlation was found related to Young's modulus or to dart impact strength.

4.1. The Impact of Blow-up Ratio (BUR) on Mechanical Properties

When correlating the BUR with the mechanical properties of the samples, an interesting result was obtained. Normally, the BUR has a direct impact on tensile properties only in the transverse direction, because the BUR is related to the width given to the product based on the amount of air contained in the bubble, which when increased, stretches the film in the transverse direction during the process. This is the case, but there was also a correlation found in the machine direction. All the values for the correlation coefficient (R^2) regarding the BUR and the four mechanical properties measured (elongation at break in the MD and TD, and tensile strength at break in the MD and TD) were between 0.91 and 0.94, as seen in Figures 4–7, as second-degree polynomial functions.

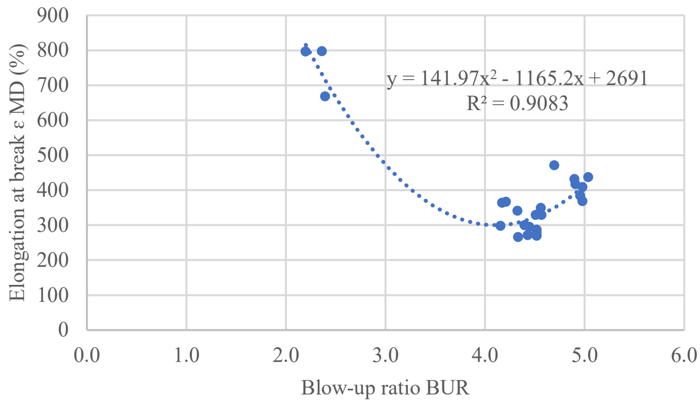

Figure 4. Polynomial correlation between BUR and ε MD.

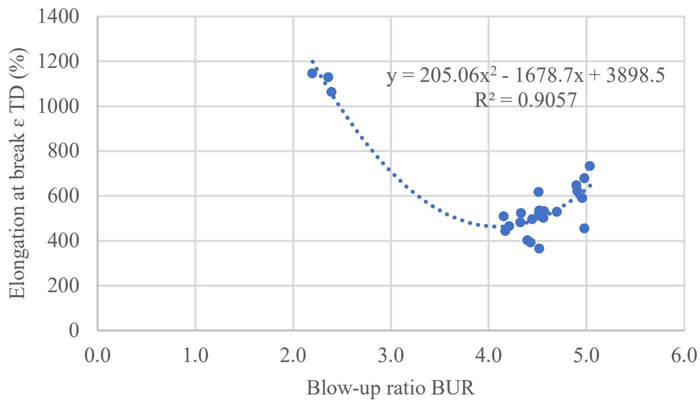

Figure 5. Polynomial correlation between BUR and ε TD.

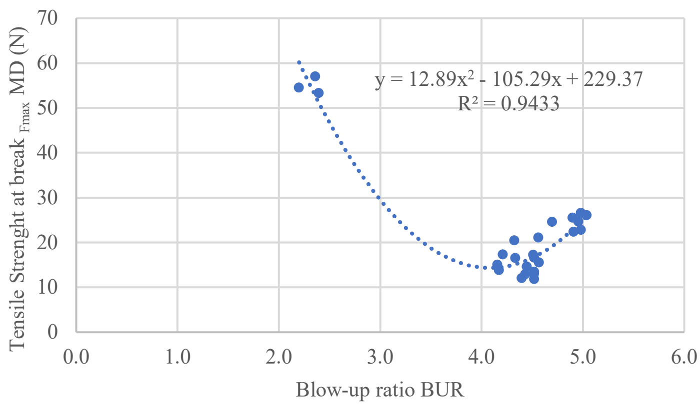

Figure 6. Polynomial correlation between BUR and F_{max} MD.

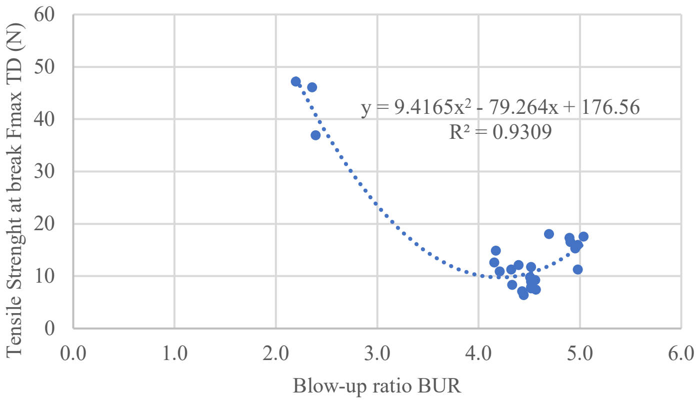

Figure 7. Polynomial correlation between BUR and F_{max} TD.

As a general observation, all the functions with the best correlation in the case of the BUR, which is mainly a parameter with an impact on axial or transverse direction properties, are polynomial second-degree functions.

4.2. The Impact of Take-up Ratio (TUR) on Mechanical Properties

In the case of the TUR, all mechanical properties' values resulted in relatively good correlation, but the elongation at break and tensile strength at break results need to be analyzed separately. Almost all functions with the highest correlation coefficients with the TUR have potential.

First, regarding the elongation at break, the differences in the correlation coefficient values as a potential function, seen in Figure 8, reflect how the TUR mainly impacts the MD orientation (R^2 = 0.90) and thus its mechanical performance. While correlation with this parameter in the TD orientation is lower (R^2 = 0.86), as seen in Figure 9, it is a polynomial second-degree function, and in Figure 10 (R^2 = 0.83) it is a potential function, like all the other properties related to the TUR. The MD correlation might be higher than the TD correlation because the TUR is related to the speed in the nip rollers that determine the thickness of the film, which occurs in the MD.

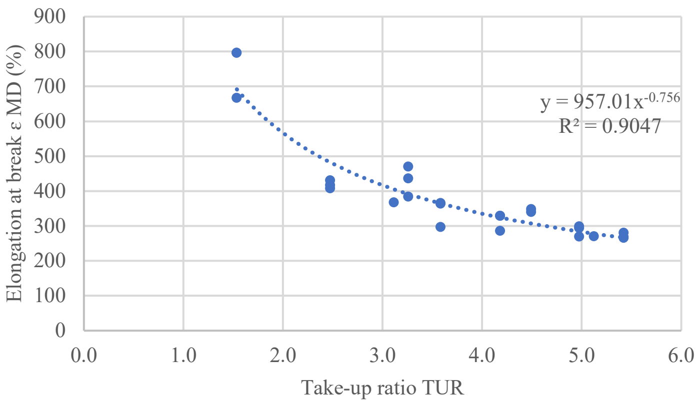

Figure 8. Potential correlation between TUR and ε MD.

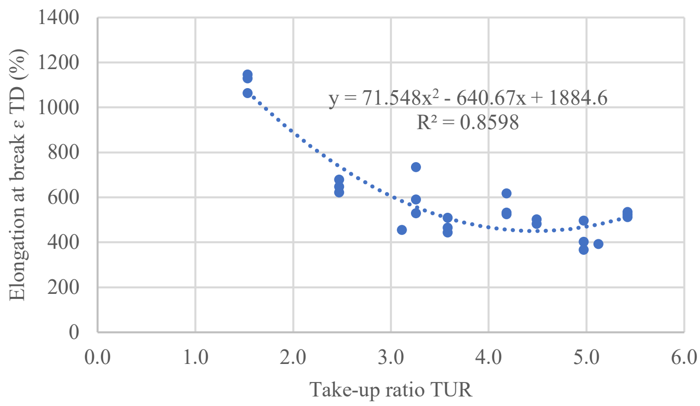

Figure 9. Polynomial correlation between TUR and ε TD.

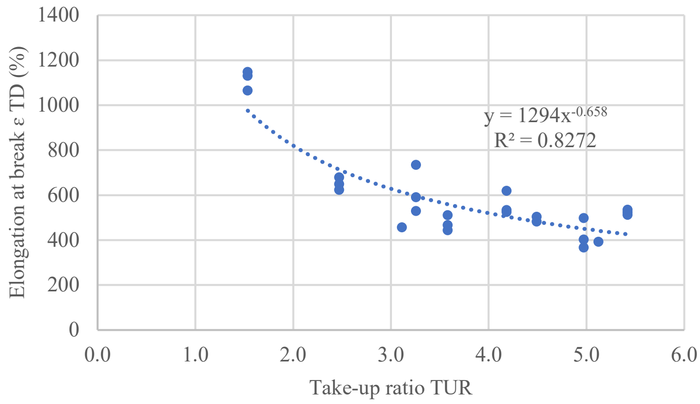

Figure 10. Potential correlation between TUR and ε TD (alternative to Figure 9).

Secondly, relating the TUR with the tensile strength at break, both in the MD and the TD, high correlations were also found (0.90 and 0.91), as seen in Figures 11 and 12, respectively.

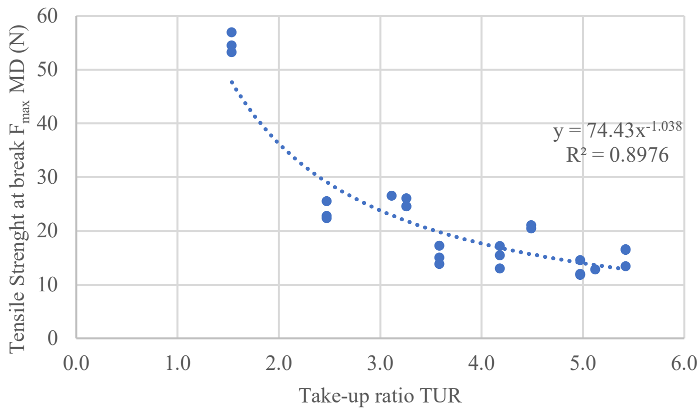

Figure 11. Potential correlation between TUR and F_{max} MD.

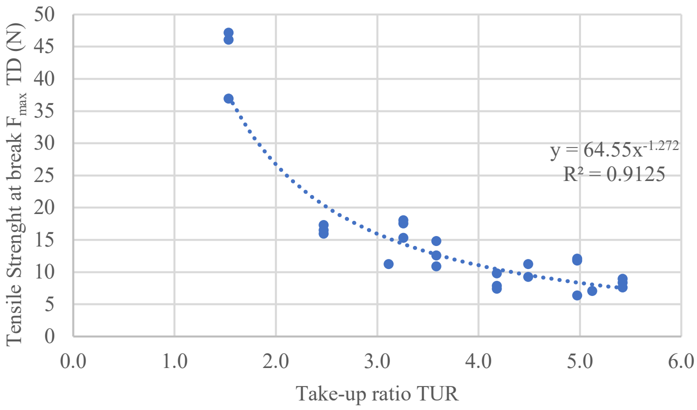

Figure 12. Potential correlation between TUR and F_{max} TD.

4.3. The Impact of Thickness Reduction (TR) on Mechanical Properties

The TR is the parameter with the highest and the lowest values in the correlation coefficients. Given that the TR is a parameter that mainly impacts the axial orientation (it is partially impacted by the expansion of the bubble to increase its diameter in the transverse direction), as does the TUR, the highest correlation coefficient occurs in the MD, both with the elongation at break in Figure 13 ($R^2 = 0.90$) and with the tensile strength at break in Figure 14 ($R^2 = 0.95$), while in the TD, the values are lower (0.85 and 0.87, respectively), as seen in Figures 15 and 16.

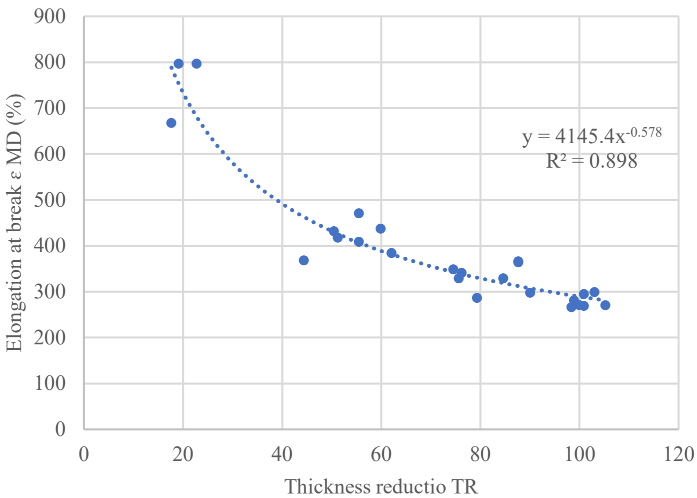

Figure 13. Potential correlation between TR and ε MD.

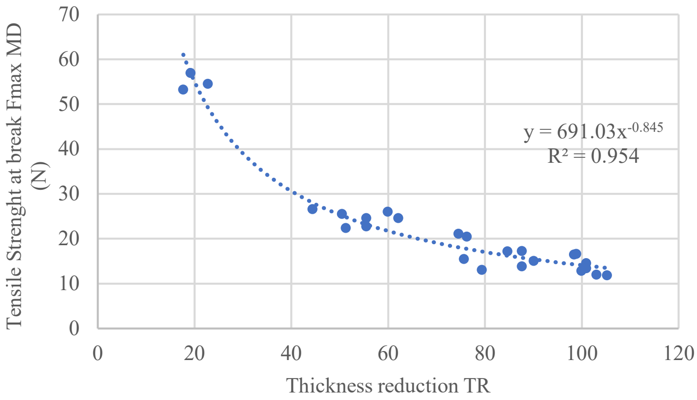

Figure 14. Potential correlation between TR and F_{max} MD.

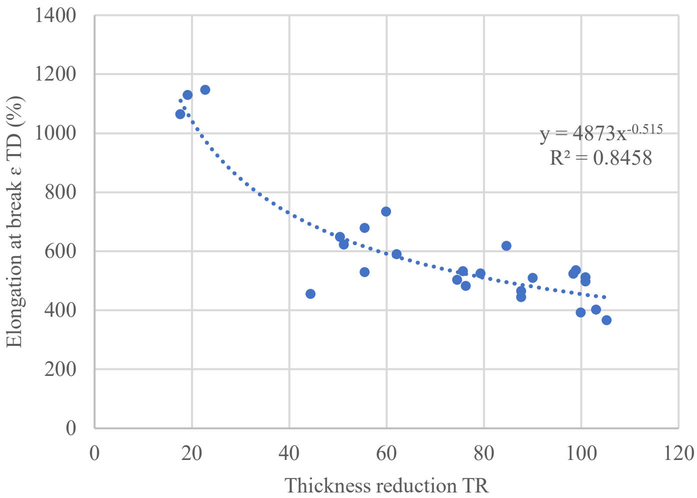

Figure 15. Potential correlation between TR and ε TD.

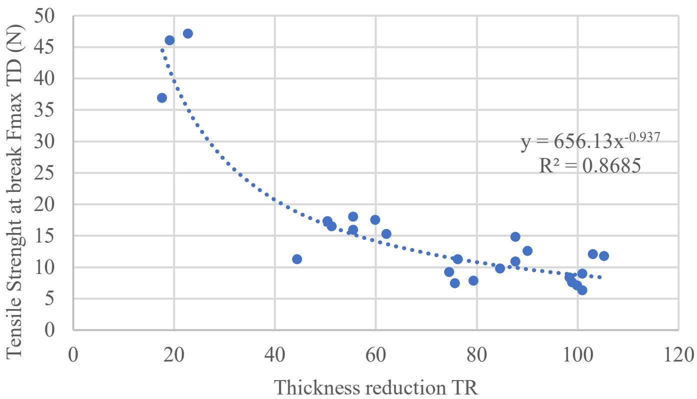

Figure 16. Potential correlation between TR and F_{max} TD.

It appears that the function that mainly represents a parameter with a transverse impact in the molecular orientation (like the BUR) is the polynomial function (second-degree), and that the function that mainly represents the axial or machine direction impact in the molecular orientation (like the TUR and TR) is the potential function.

Nevertheless, there are some cases in which a relatively high correlation is seen between the BUR and MD properties and between the TUR and TD properties. This may be because the FR is close to one (between 0.5 and 1.2), indicating a very good symmetry of stretching in both directions, while in other cases it could have values higher than 30, having, for example, a BUR = 2 and a TUR = 60 [6].

These results imply that, during the extrusion process, if the BUR, TUR and TR process parameters are kept under control, the value of tensile elongation at break and tensile strength at break in both the machine direction and the transverse direction can be predicted and determined. It also fits with the conclusions from Auksornkul et al. [8], who found that increasing the BUR yielded a higher TD molecular orientation, resulting in increased TD tensile strength and faster cooling, resulting in a lower crystallite orientation and increasing the elongation at break. These findings can be particularly considered in the design of new products, so that when changing specifications, product properties can be maintained in such a way that it is functional for customer needs.

5. Conclusions

This study analyzed how the main process parameters affect the mechanical properties of HDPE and LLDPE blend plastic bags. All the samples were manufactured on an industrial scale. The highest dart impact strength was found in the samples that were manufactured with neck height values between eight and eleven times the die diameter. It was observed that the dart impact strength has a relationship with the thickness (inversely) and with the neck height (directly). It was also found that there is a correlation between various elongation properties and blown film process parameters (R^2 approximately between 0.90 and 0.95). The majority reflect the BUR related to TD properties, and the TUR and TR related to MD properties, although in some cases, the BUR correlates with the MD and the TUR correlates to the MD probably, because of the FR value close to one.

For future studies, it is recommended to extend the experimental study to be able to correlate the neck height with the dart impact strength. In addition, it would be important to carry out a study in which the morphology of the sample materials is related to other properties after changes in the process. Carrying out these studies in the future will allow us to have information regarding relationships that are applicable to various types of plastic industries that use blown film extrusion as a production process.

Author Contributions: Conceptualization, F.C., A.C., and E.R.; methodology, F.C.; formal analysis, F.C., A.C., and E.R.; investigation, F.C., A.C., and E.R.; resources, E.R. and A.C.; writing—original draft preparation, F.C.; writing—review and editing, E.R. and A.C.; supervision, A.C. and E.R.; project administration, E.R. and A.C.; funding acquisition, A.C and E.R. All authors have read and agreed to the published version of the manuscript.

Funding: This work has been done in the frame of Project PID2022-143329OA-I00 of the Spanish Ministry of Science and Innovation and funded by the Industrial Engineering School-UNED through grant of reference 2023-ETSII-UNED-05.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: We would like to acknowledge the Research Group of the UNED, "Industrial Production and Manufacturing Engineering (IPME)", and the "Master in Advanced Manufacturing Engineering" for their given support.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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