Bitlis Eren Üniversitesi Fen Bilimleri Dergisi

BİTLİS EREN UNIVERSITY JOURNAL OF SCIENCE
ISSN: 2147-3129/e-ISSN: 2147-3188
VOLUME: 13 NO: 1 PAGE: 182-191 YEAR: 2024
DOI:10.17798/bitlisfen.1370130

Analysis of Mechanical Properties of EVOH/LDPE Films Produced with Waste EVOH and LDPE

Yunus Emre DUYĞUN[1], Münir TAŞDEMİR[2*]

[1]*Marmara University, Institute of Pure and Applied Science, Department of Metallurgical and Materials Engineering, Istanbul, Türkiye*
[2]*Marmara University, Technology Faculty, Department of Metallurgical and Materials Engineering, Istanbul, Türkiye*

(ORCID: 0000-0002-5636-0254) (ORCID: 0000-0001-8635-7251)

Keywords: Low density polyethylene, poly(ethylene-co-vinyl alcohol), flexible packaging, recycling, multi-layer films.

Abstract
The importance of plastic materials continues to develop more and more every year from past to present. As important as the plastics used in almost every area of life are, it is equally important to keep these materials in the environmental cycle. Since 1970, the use and consumption of plastic has increased almost 10 times. A large share of the use of these plastics occurs in the flexible packaging sector. In the multi-layer films used on flexible packaging in the packaging industry, one of the most important issues of the future is the crisis of raw materials, and the other is recycling and sustainability. In this study, it is aimed to evaluate the low density polyethylene/ poly(ethylene-co-vinyl alcohol)/low polyethylene (LDPE/EVOH/LDPE) structured flexible packaging film waste produced by multilayer blown extrusion method within the same LDPE/EVOH/LDPE flexible packaging film and to examine the mechanical property changes of the material. Sustainable environment and economy, reducing the cost of raw materials, obtaining approximately similar mechanical properties are among the objectives of the study. The wastes released from the LDPE/EVOH/LDPE film were granulated in a single screw extruder. Then, the amount of these waste EVOH granules was 5%, 10%, 20% and 25% by weight in the total film, and their production was carried out with reference to the pure EVOH film in a 7-layer blown film extruder. Samples were taken from the films produced in 50μm thickness in accordance with the standards. Tensile test, tear test, puncture resistance test, sealing force test, shrinkage tests were performed. According to the results of the tests, analyzes on the use of scrap EVOH were concluded.

1. Introduction

The demand for the packaging industry, which is one of the most important branches of the plastics industry, is increasing day by day. In the packaging industry, various product groups are produced with superior features that can meet the sectoral needs in both rigid and flexible packaging categories. Various packaging demands of many fields such as food, non-food, medicine, hygiene are provided with flexible packaging. Film structures suitable for the desired properties can be provided with multi-layer film production. Multi-layer films can be produced in layers according to the desired mechanical, physical, light transmittance and barrier properties, similar to composite materials. This situation plays a very important role in increasing the demand of the flexible packaging industry [1]. With the rapid growth of the sector, the acceleration of production processes, and the development of technology, environmental economy and sustainability have increased their importance. Many sustainable solutions such as reusing packaging waste, reducing raw material consumption, reintroducing them into production methods, creating films with a uniform material have begun to be produced and legally implemented [2]. At

* Corresponding author: *munir@marmara.edu.tr*

Received: 02.10.2023, Accepted: 26.02.2024

this point, starting from the general structures of polymers, studies on the structures of materials and their reuse are increasing. Mechanical and chemical recycling methods are the most preferred recycling methods [3].

In this study, four different weight ratios of LEL (LDPE/EVOH/LDPE) scrap were added (5%, 10%, 20% and 25%) to the LEL film produced with a 7-layer blown extruder, with a total thickness of 50 microns, in order to contribute to the raw material problems experienced in the packaging industry and to reduce environmental pollution. After feeding PE-g-MA as compatibilizer at certain rates and reuse in LEL film, the mechanical properties of the material were examined in detail.

2. Material and Method

2.1 Material

Low density polyethylene (LDPE 310 E), polyethylene grafted maleic anhydride (Bynel 4157) from Dow Chemical Company and polyethylene grafted maleic anhydride (PE-g-MA) (Retain 3000) specially produced for waste use, low density polyethylene (Enable 2010 Series Blown 2010MA) from Exxon Mobil, ethylene vinyl alcohol (Evasin EV3251F) from Chang Chun Petrochemicals and, finally, granulated waste PE/EVOH granule from production.

2.2 Preparation of waste LEL granules with a single screw extruder

During the production of 50 micron thick multi-layer LEL films, the waste, waste and parts that are shaved off the reel are set aside. It was stored in baskets and decomposed to be re-extruded into the Erema single screw extruder. Clipped flexible packaging waste is placed on the belt system. After feeding, firstly, before entering the extruder, the clipped films were pre-grinded at 104°C in the pre-grinder part of the Erema machine in order to make them smaller and easier to process, and the waste films were mixed within themselves and divided into smaller pieces. After this process, the clipped waste films were fed into the Erema single screw extruder, which has a total of 7 heating zones. It was ensured that the material became molten in the temperature range of 120°C-200°C at a speed of 240 rpm. Extruder operating temperatures are shown in Table 1 below.

Table 1. Working range of single screw extruder

	Heating zones							
Process	1	2	3	4	5	6	7	Die
Temperature (°C)	130	190	190	200	190	200	200	230

Pressure average 160 bar and screw rotation speed 240 rpm

Afterwards, the melt that came out in the form of spaghetti from the perforated area in the head area was divided into small pieces with the help of a knife and cooled in cooling water at approximately room temperature. In the cooling process, the cooled granules were sieved with vibration. As a final process, the granule, which was transported to the dryers, was dried and filled into 25 kg sacks. The waste films passed through the single screw extruder and the last granules are shown in Figure 1.

(a) (b)

Figure 1. Granules produced from single screw extruder
a) waste LEL flexible packaging films
b) waste LEL granules

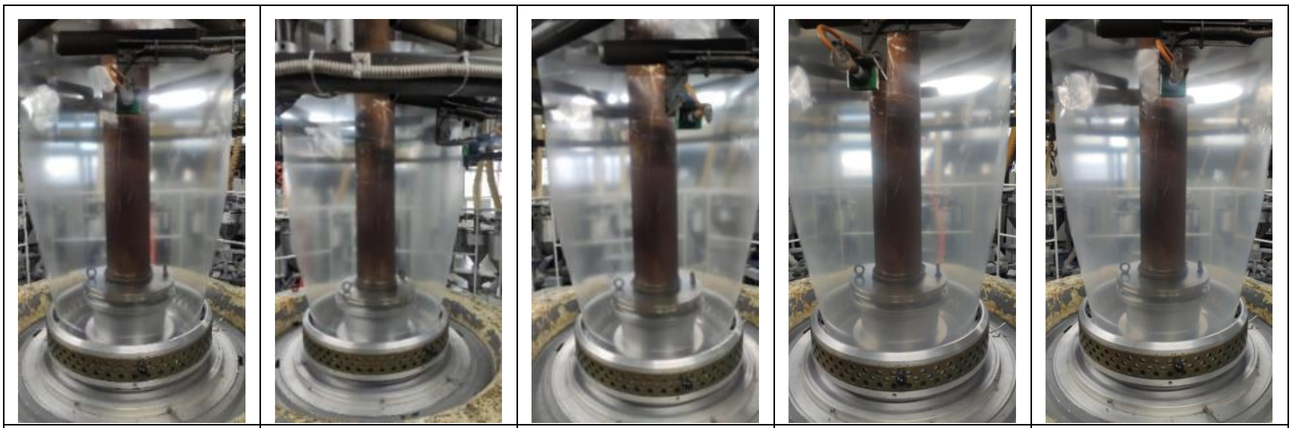
2.3 Use of waste LEL granules with multi screw extruder

The obtained waste LEL granules are now in a form suitable for use in the multilayer extruder. With the 7-layer Kiefel Kirion model blown extruder, 50μ thick films with different waste LEL ratios were produced. In the 7-layer extruder, the recipe of the film was created for the layer distributions shown in Table 2. The indicated plies A-B-C-D-E-F-G refer to each screw-sleeve in the multilayer extruder film. Layers A-B and F-G represent the layer on which the LDPE and LLDPE polymer is fed. C and E layers represent the adhesive (tie) layer. The D layer is the barrier layer where the EVOH material is fed. As seen in Table 3 in the contents of the films produced, a total of 5 different barrier extruder films were produced, of which 5%, 10, 20 and 25 by weight of the film contains waste and in pure form. During production, waste-free pure LEL film was produced primarily for reference. In Table 2, the ratio of waste LEL in the total film was calculated as a weight ratio of 50µ film.

Table 2. Seven layer extruder floor distributions total 50µ

A Screw 1 13µ	**B Screw2 7µ**	**C Screw 3 4µ**	**D Screw4 2µ**	**E Screw 5 4µ**	**F Screw6 7µ**	**G Screw7 13µ**
LDPE LLDPE	LDPE LLDPE	g-maleic anhydrite LDPE	EVOH	g-maleic anhydrite LDPE	LDPE LLDPE	LDPE LLDPE

Adhesive solid waste LEL ratio was calculated with the ratio of the weight of the C and E screws to the 50µ film. Likewise, the ratio of LDPE solid waste LEL was calculated with the ratio of the total weight of A-B-F-G screws to 50µ film. The ratio of adhesive layer Retain 3000 was calculated by the ratio of C and E screws, and the ratio of LDPE layer Retain 3000 by weight of A-B-F-G screws to 50µ film. Table 3 shows the ratios of waste LEL used in the extruder layers. The images of the films coming out of the extruders are shown in Figure 2.



Pure LEL	%5 Waste LEL	%10 Waste LEL	%20 Waste LEL	%25 Waste LEL

Figure 2. Output of films with different waste LEL ratio from the extruder heat

Table 3. Waste LEL mixing ratios by weight

50 Micron	Tie (C-E) layers waste LEL rate[1] (%)	Tie (C-E) layers Retain 3000 rate (%)	LDPE (A-B-F-G) layers waste LEL rate[1] (%)	LDPE (A-B-F-G) layers Retain 3000 rate (%)
Pure LEL	-	-	-	-
%5 waste LEL	0	0	17,25	0,5
%10 waste LEL	25	0,5	27,5	1
%20 waste LEL	50	1	41,5	1,5
%25 waste LEL	50	1,5	55	2

[1] *waste LEL contains 5% EVOH granules*

3. Results and Discussion

3.1 Tensile strength

The maximum tension value that flexible packaging films can withstand is defined as tensile strength. The tensile behavior of flexible packaging films is tested in the machine direction and transversely. This situation is also called machine longitudinal and machine transverse samples. The tensile strength value is expressed in MPa. Tensile strength, σÇ: Tensile strength, Pmax.: It is measured as the ratio of maximum force to A0: initial surface area [4].

$$\sigma Ç = P_{max} / A_0 \qquad (1)$$

The graphical expression of the values is shown machine direction (MD) in Figure 3 and cross direction (CD) in Figure 4. According to the test results, it was observed that the tensile strength values decreased as the amount of waste LEL granule increased in the MD and CD tensile strength results. The tensile strength values of 26,60 MPa MD and 23,40 MPa CD tensile strength were measured in pure LEL material. When 5% waste LEL granules were added, the MD tensile strength decreased by 4%, while the CD tensile strength decreased by 4,3%. When the waste LEL granule ratio was increased to 10%, the MD tensile strength decreased by 10,3% compared to the pure LEL film, while the CD tensile strength decreased by 6,2%.

When the amount of waste LEL granule was increased to 25%, the MD tensile strength value decreased by 17,1% compared to the pure LEL film, while the CD tensile strength decreased by 12,2%. In general, it was observed that as the amount of waste LEL granules increased, the CD and MD tensile strength values decreased. When Feng et al. followed the mechanical behavior of the material with LDPE and EVOH films and foams with different ratios of mixtures, they observed that the tensile strength decreased with the increase in the amount of LDPE foam [5]. Chi-Hsien Huang et al. observed that the tensile strength of the material decreased with the increase of the amount of PE-g-MAH in the PE/EVOH mixture [6]. In a study by Kalfoglou et al., when the compatibility of Poly(ethylene-co-vinyl alcohol) and EVOH-HDPE mixtures was examined, it was observed that the tensile strength value decreased as the amount of SEBS-g-MA was added to the film prepared with the melt mixture [7].

In this study, we can say that there is a decrease in mechanical tensile strength since the amount of LDPE by weight increases in the waste LDPE and EVOH granules added and incompatible regions are formed.

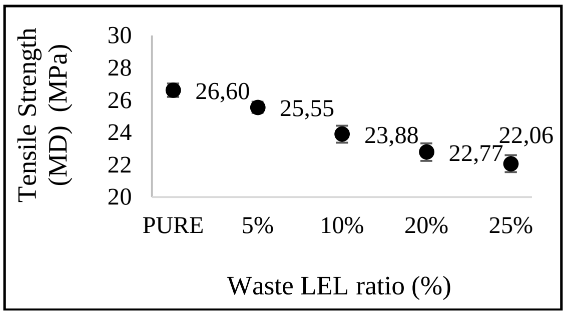


Figure 3. Graphical representation of MD tensile strength values of LEL films

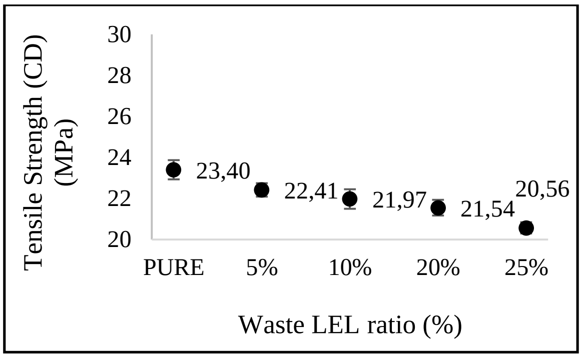


Figure 4. Graphical representation of CD tensile strength values of LEL films

3.2 Breaking strength

The part where the flexible packaging films break after a certain tension value is defined as the breaking strength. Tensile strength is measured in the same way as tensile strength in 2 regions, machine direction (MD) and cross direction (CD). The breaking strength values are expressed in MPa. The graphical expression of the values is shown MD in Figure 5 and CD in Figure 6. According to the test results, it was observed that as the amount of waste LEL granule increased in the MD and CD tensile strength results, there was a decrease in the breaking strength values similar to the tensile strength. In pure LEL material, 26,18 MPa MD and 23,41 MPa CD breaking strength values were measured. When 5% waste LEL granules were added, the MD breaking strength decreased by 4,4%, while the CD breaking strength decreased by 4,9%. When the ratio of waste LEL granule was increased to 10%, the MD breaking strength decreased by 13,3% compared to the pure LEL film, while the CD breaking strength decreased by 7,9%. Compared to the pure LEL film, the MD breaking strength of the film containing 20% waste LEL granules decreased by 16,7%, while the CD breaking strength decreased by 11,4%. When the amount of waste LEL granule was increased to 25%, the MD breaking strength value decreased by 21% compared to the pure LEL film, while the CD breaking strength decreased by 14,4%. In general, it was observed that as the amount of waste LEL granules increased, the CD and MD breaking strength values decreased. This situation can be interpreted as the decrease in breaking strength with the increase of the void structure between the polymers.

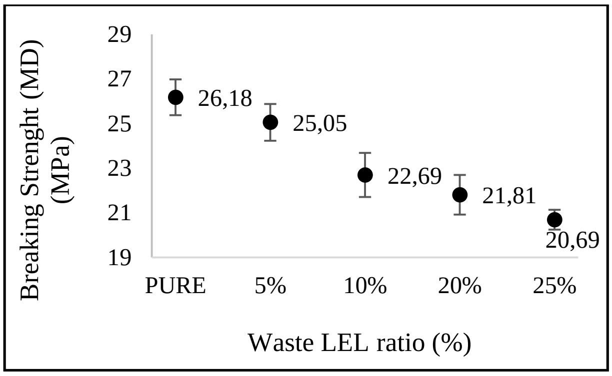


Figure 5. Graphical representation of the MD breaking strength values of LEL films

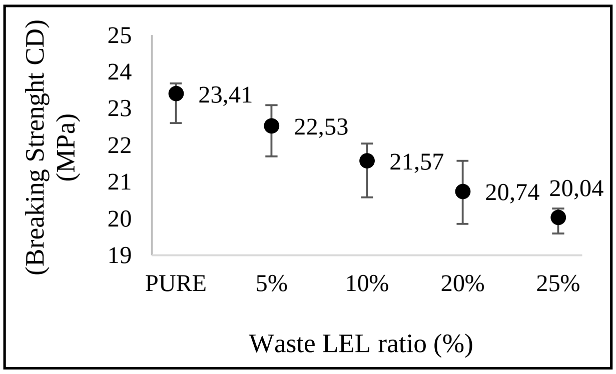


Figure 6. Graphical representation of the CD breaking strength values of LEL films

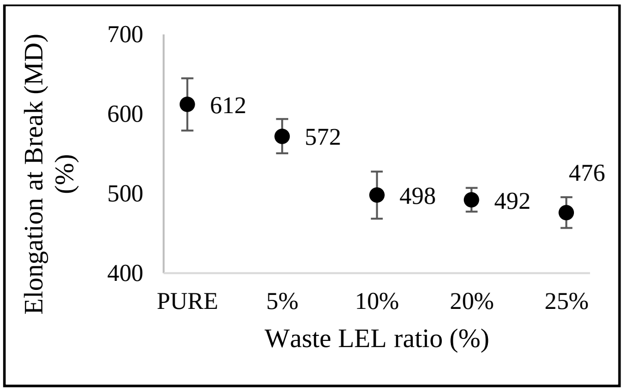


Figure 7. Graphical representation of MD elongation at break values of LEL films

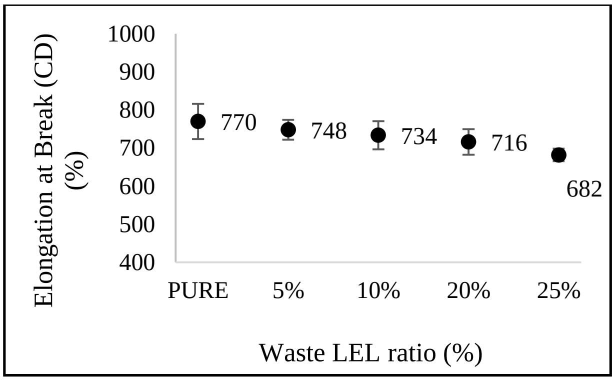


Figure 8. Graphical representation of CD elongation at break values of LEL films

3.3 Elongation at break

In the tensile test of flexible packaging films, the maximum elongation rate that occurs in the material is defined as the elongation at break. In the elongation at break, comments are made about the ductile structure and brittleness of the material. The elongation at break is expressed in %. The decrease in the ductility of the material in flexible packaging films reduces the elongation of the film. The elongation at break is also measured in the tensile test, both MD and CD. The graphical expression of the values is shown MD in Figure 7 and CD in Figure 8. In a study conducted by Saini et al., they found that the elongation at break value decreased when the composite material was made with a mixture of PE-g-MAH material and paper powder in different weight ratios [8].

According to the test results, a similar decrease in elongation at break values was observed as the amount of waste LEL granule increased in the MD and CD elongation results. In pure LEL material 612% MD and 770% CD elongation at break were measured. When 5% waste LEL granules were added the MD elongation at break decreased by 6,6%, while the CD elongation at break decreased by 2,9%. When the ratio of waste LEL granule was increased to 10%, the MD elongation at break decreased by 18,7% compared to the pure LEL film, while the CD elongation at break decreased by 4,7%. While the MD elongation at break of the film containing 20% waste LEL granules decreased by 19,7% compared to the pure LEL film, the CD elongation at break decreased by around 7,1%. When the amount of waste LEL granule was increased to 25%, the MD elongation at break decreased by 22,3%, while the CD elongation at break decreased by 11,5% compared to pure LEL film. In general, as the amount of waste LEL granules increased, it was observed that the elongation at break decreased in both CD and MD. This can be interpreted as the ductility of the flexible film decreases as the amount of waste increases. The reason for this can be interpreted as the fact that the materials mixed in the molten state could not bond with each other to form long chains.

3.4 Tear force

The tear strength of flexible packaging films is measured by the resistance of the sample against tearing. During the tear test, the tear value of the material at a given load is measured in mN using the elmandorf tear method. The higher the tearing force of the film, the higher the tear resistance of the material. The test is measured by determining the average force to propagate the tear across a specified length of plastic film or non-rigid sheet after tearing has begun, using an Elmendorf type tear tester [9]. In the application of the test, samples were prepared in the form of a rectangular plate with a width of 76 mm and a length of 63 mm. Afterwards, the test was carried out with a load of 800 g, both transversely and longitudinally. Tear resistance is also measured both in MD and CD. The graphical expression of the values is shown in Figure 9 for the MD tearing force, and in Figure 10 the CD tearing force is shown. According to the test results, it was observed that there was a similar decrease in the tearing force values as the amount of waste LEL granule increased in the MD and CD shear force results. In pure LEL material, 4434 mN MD and 5378 mN CD shear forces were measured. When 5% waste LEL granules were added, the MD tear force value decreased by 11,5%, while the CD tear force value decreased by 7,4%. When the ratio of waste LEL granule was increased to 10%, the MD tearing force value decreased by 15,8% compared to the pure LEL film, while the CD tearing force value decreased by 12%. The MD tearing force value of the film containing 20% waste LEL granules decreased by 31,3%, while the CD tearing force value decreased by around 33,2% compared to the pure LEL film. When the amount of waste LEL granule was increased to 25%, the MD tearing force value decreased by 39,4%, while the CD tearing force value decreased by 48% compared to the pure LEL film. In general, as the amount of waste LEL granule increased, there was a clear decrease in the CD and MD tearing force value. The decrease in this tearing force can be interpreted as the fact that the material is more brittle, its ductility decreases and its resistance to tearing decreases. In a different study by Huang, C. H et al., they observed that the tear strength of the film decreased with the increase in the amount of PE-g-MAH used in the EVOH and LDPE mixture [10].

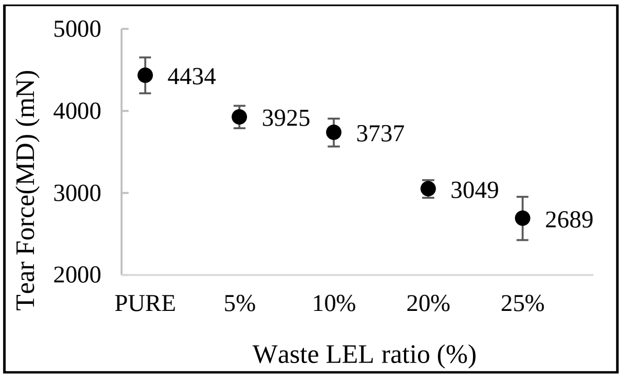


Figure 9. Graphical representation of MD tearing force values of LEL films

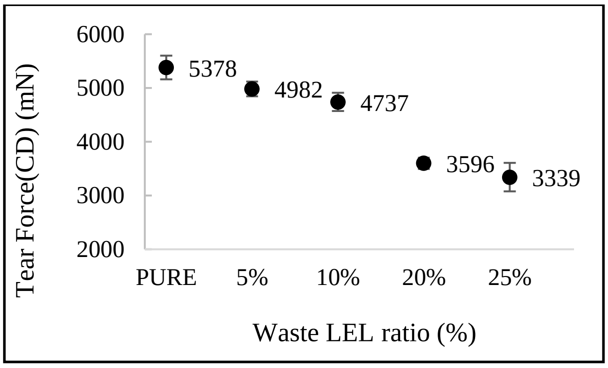


Figure 10. Graphical representation of MD tearing force values of LEL films

3.5 Puncture resistance

In flexible packaging films, the puncture resistance of the material expresses the maximum point at which it resists a probe as the puncture force. Materials with high puncture strength are generally referred to as ductile materials [11]. Test results are expressed in N. The graphical expression of the values is shown in Figure 11.

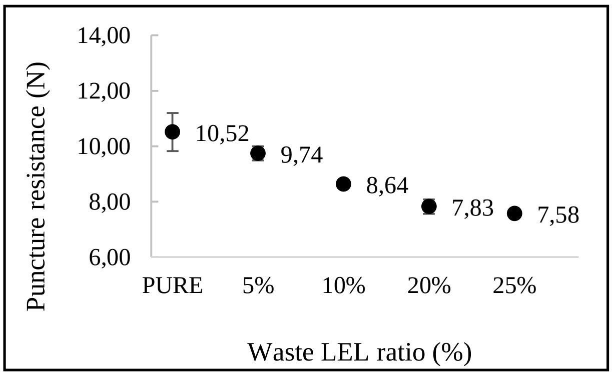


Figure 11. Graphical representation of puncture force values of LEL films

According to the test results, it was observed that the puncture resistance values decreased as the amount of waste LEL granules increased in the puncture resistance results. The puncture resistance value of 10,52 N was measured in pure LEL material. The puncture resistance value of 5% waste LEL granules decreased by 7,5%. When the ratio of waste LEL granules was increased to 10%, the puncture resistance value decreased by 17,9% compared to pure LEL film. The puncture resistance value of the film containing 20% waste LEL granules decreased by 25,6% compared to the pure LEL film. When the amount of waste LEL granule was increased to 25%, the puncture resistance value decreased by 28% compared to the pure LEL film. In general, the puncture resistance of the material decreased as the amount of added waste increased.

3.6 Seal breaking strength

Determination of seal strength on flexible packaging films is a test method for the determination of the adhesion force of a material to itself or to another surface. Here, the breaking strength value is found by the ratio of the force per unit area in the region where the film is sealed [12]. LEL films were sealed between 110°C-130°C-150°C and 170°C and the breaking strength was expressed in N/mm2. The high seal break strength of a flexible packaging film means that the material itself or the adhesion force on the different surface to which it is attached is high and it is a strong seal. According to the test results graphical expression of the values is shown in Figure 12.

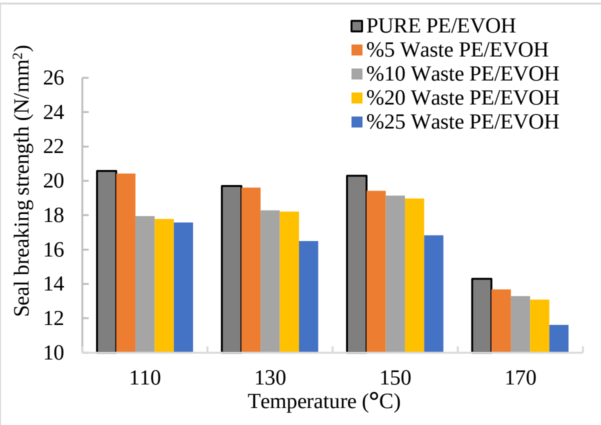


Figure 12. Graphical representation of seal breaking strength values of LEL films

According to the test results, it was observed that as the amount of waste LEL granule increased in the seal breaking strength results, there was a decrease in the seal breaking strength values at 110°C-130°C-150°C and 170°C temperatures. In pure LEL material, seal breaking of 20,5 N/mm2 at 110°C, 19,7 N/mm2 at 130°C, 20,3 N/mm2 at 150°C and 14,3 N/mm2 at 170°C strength was measured. When 5% waste LEL granules were added, the seal breaking strength decreased by 0,7%, 0,6%, 4,4% and 4,4% at temperatures of 110°C-130°C-150°C and 170°C, respectively. When the waste LEL granule ratio is increased to 10%, the seal breaking strength value is 12,8%, 7,3%, 5,7% and 7,1% at 110°C-130°C-150°C and 170°C temperatures, respectively, compared to pure LEL film rate decreased. The seal breaking strength value of the film containing 20% waste LEL granules compared to the pure LEL film was 13,7%, 7,7%, 6,5% and 8,5% decreased respectively at 110°C-130°C-150°C and 170°C temperatures. When the amount of waste LEL granule is increased to 25%, the seal breaking strength values compared to pure LEL film are 14,6%, 16,3%, 17,1% and 18% decreased respectively at 110°C-130°C-150°C and 170°C temperatures. According to the results here, it can be interpreted that the increase in the amount of waste in the material decreases the adhesion of the chains to each other with the increase of the adhesion force on the source surface of the film. At the same time, the material was deformed when sealed at 170°C. In a study by Giovanni De Martino et al., they compared the production of barrier films in 5, 7 and 9 layer extruders. Here, in the seal data, it was observed that as the number of extruder layers increased, the seal strength increased [13].

3.7 Seal elongation at break

In the determination of the sealing elongation at break of flexible packaging films, it is measured as the amount of elongation of the film made under a certain tension when it reaches the breaking point. LEL films were sealed between 110°C-130°C-150°C and 170°C and elongation at break expressed in %. The elongation at break of a flexible packaging film means that the adhesion force on the material itself or on the different surface to which it is attached is high, and the material elongates in the sealed area. According to the test results graphical expression of the values is shown in Figure 13.

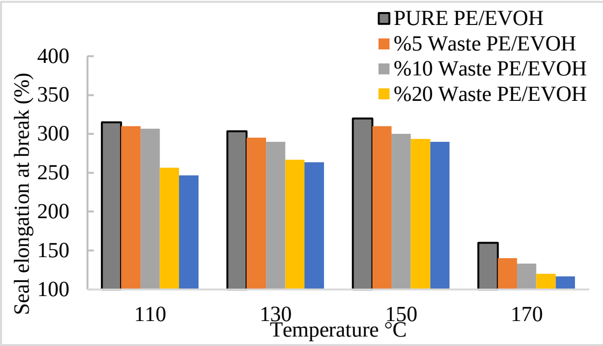


Figure 13. Graphical representation of seal elongation at break values of LEL films

According to the test results, it was observed that as the amount of waste LEL granule increased in the seal elongation results, there was a decrease in the seal elongation values at 110°C-130°C-150°C and 170°C temperatures. In pure LEL material, 315% at 110°C, 303% at 130°C, 320% at 150°C and 160% at 170°C were measured. When 5% waste LEL granules were added, seal break elongation decreased by 1,6%, 2,7%, 3,2% and 12,5% respectively at 110°C-130°C-150°C and 170°C temperatures. When the ratio of waste LEL granule is increased to 10%, the weld elongation value is 2,6%, 4,2%, 6,2% and 16% decreased respectively at 110°C-130°C-150°C and 170°C degrees compared to pure LEL film. The seal elongation value of the film containing 20% waste LEL granules decreased by 18,5%, 11,9%, 8,5% and 25% respectively at 110°C-130°C-150°C and 170°C degrees compared to the pure LEL film. When the amount of waste LEL granule is increased to 25%, the seal elongation value compared to pure LEL film is 21,6%, 23,2%, 9,4% and 26% decreased respectively at 110°C-130°C-150°C and 170°C temperatures. According to the results here, the increase in the amount of waste in the material adversely affected the elongation values of the film. A significant decrease in elongation values at 170°C led to the conclusion that the material combustion at this temperature and the film became embrittled.

3.8 Shrinkage rate

The shrinkage rate gives the shrinkage value of the flexible packaging film when it is cooled under a certain temperature, after a certain period of time. At this point, the shrinkage rate of the flexible packaging film is determined as % according to the rate of the first and last measurements. The fact that this value is low is interpreted as the decrease in the central melting point of the film under a certain temperature and time, and the decrease in the threshold energies of the polymer chains and the weakening of the bonds by breaking [14]. The high shrinkage rate of a film indicates the stable position of the film in its form. The graphical expression of the values is shown in Figure 14. As seen in the graph, as the waste LEL ratio increased, the shrinkage ratio decreased.

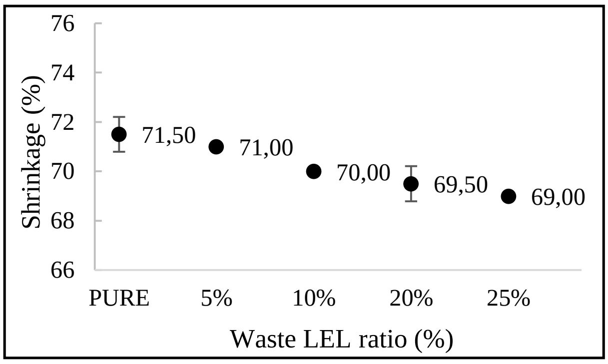


Figure 14. Graphical representation of shrinkage values of LEL films

3.9 Polarized optical microscope

In Figure 15, the black parts are the parts where the test sample is held. The region of scaling is the part where the sample is located. The first region is the LDPE and g-maleic anhydride layers, the middle part is the EVOH layer and again symmetrically the LDPE and g-maleic anhydride layers. Based on the microscope images, it has been observed that the clean appearance of the layers in the cross-sectional area gradually deteriorates with the increase in the amount of waste. Total film thickness was measured as 50,22 µm in the a, pure LEL sample. LDPE and adhesive layer were measured as 22,35 µm on the left side of the sample and 22,90 µm on the right side of the sample, similar to a single layer by interfering with each other. In the EVOH layer, the measurement was taken as 1,93 µm. The total film thickness was measured as 51,60 µm in b, which is a 5% waste LEL sample. Here too, the LDPE and adhesive layers interfere with each other and are measured as 22,35 µm on the left side of the sample sample and 24,01 µm on the right side, similar to a single layer. A similar measurement was observed as 1,93 µm on the EVOH layer. Total film thickness was measured as 51,05 µm in c, which is 10% waste LEL sample. Here, again, the LDPE and adhesive layers interfere with each other, and the left part of the sample sample is measured as 21,80 µm and the right part as 22,63 µm. The EVOH layer is seen as 1,94 µm. At this point, it is seen that the homogeneous appearance of the material among each other begins to decrease compared to the pure state in the LDPE adhesive layers. A total film thickness of 5,.36 µm was measured in d, a 20% waste LEL sample. Likewise, the LDPE and adhesive layers interfered with each other, and the left part of the sample sample was measured as 22,49 µm and the right part as 22,35 µm. Although the EVOH solid was measured as 1,93 µm, thinning and thickening started to increase. In the image here, it is seen that the homogeneity of the film has decreased and the indentation has increased. A total film thickness of 50,64 µm was measured in e, a 25% waste LEL sample. Similar to 20% waste LEL film, the interference of LDPE and adhesive layer measured 21,80 µm on the left and 22,63 µm on the right. The EVOH solid was measured as 1,93 µm and showed more indentations than 20% waste LEL film. When Lılı Wang's study on the effect of regrind content on PP-EVOH sheet properties and the effect of orientation on the permeability of EVOH multilayer films was examined, they observed that the adhesive layer and PE material interfered more with each other at different BUR rates and tension [15]. In the study conducted by Yiwu Liu and his colleagues, it was determined under the microscope that when the EVOH/nano SiO2 film was produced in the twin screw extruder by melt blending and inflation and production in the extruder, the brightness value increased inversely proportional to the decrease in haze [16].

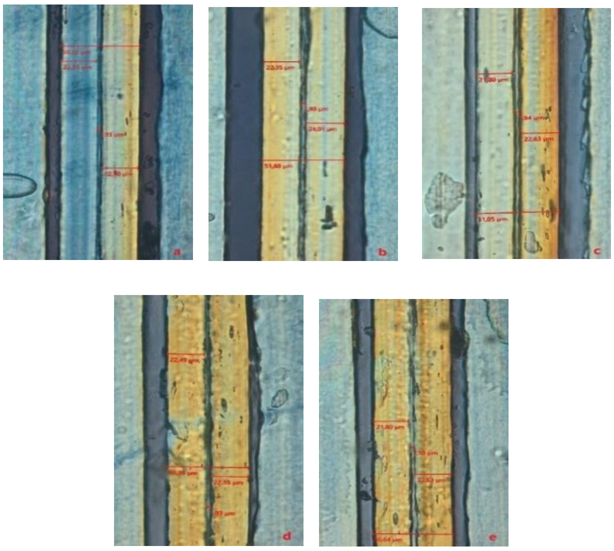


Figure 15. Microscopic views of LEL films formed with waste EVOH and LDPE a) Pure LEL, b) 5% waste LEL, c) 10% waste LEL, d) 20% waste LEL, e) 25% waste LEL

4. Conclusion and Suggestions

In this study, after the waste LEL films were granulated, they were successfully used again in LEL multilayer films. In general, a decrease in the mechanical values of the flexible packaging film was observed with the increasing amount of waste LEL granules. When the tests performed on the barrier flexible packaging films containing waste LEL granules are examined; It was observed that the tensile strength and breaking strength values in mechanical values decreased both in machine length and width. The tensile elongation and elongation at break were also found to decrease gradually. Looking at the elastic modulus, it was seen that the modulus of elasticity decreased as the amount of waste of the material increased, along with the decrease in tensile and elongation data. In the control of tearing forces, it was observed that as the amount of waste increased, there was a decrease in the longitudinal and transverse tearing forces. In parallel with the puncture resistance results, the increase in the amount of waste weakened the puncture resistance of the material. When the films with different temperatures and waste LEL granule ratios were examined during the control of seal breaking force and elongation at break, a decrease was observed in the values in this part as well. During the shrinkage control, it was determined that the amount of shrinkage of the material increased. During the control under the polarized optical microscope, it was determined that the amount of waste increased and the cross-sectional area of the film was defected. Considering these points, it can be said that the Retain 3000 (MAH g-PE) material used is fed in multilayer extruders at different rates, giving a successful appearance to the film containing up to 20% waste LEL granules and promising for its development.

Acknowledgment

We would like to thank Korozo Packaging company for providing all production and test support to our work.

Contributions of the authors

The authors performed the experiments together, analyzed the results and performed the writing process together.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics

References

[1] https://www.globenewswire.com/en/news-release/2022/07/05/2474204/0/en/Europe-Flexible-Packaging-Market-to-Projected-to-Cross-USD-71-3-Billion-by-2028-BlueWeave-Consulting.html, Access:2022.

[2] TMMOB Kimya Mühendisleri Odası İstanbul Şubesi Plastik ve Kauçuk Komisyonu, 2021, Türkiye`de Plastik Geri Dönüşümü ve Atık İthalatı Raporu, 5.

[3] O., Horodytska, F. J., Valdés, A. Fullana, "Plastic flexible films waste management–A state of art review", *Waste management*, vol.77, pp.413-425, 2018.

[4] ISO 527-1 Plastics—Determination of tensile properties—Part 1: General principles. International Organization of Standardization: Geneva, Switzerland, 2024.

[5] J., Feng, Z., Li, A., Olah, E. Baer, "High oxygen barrier multilayer EVOH/LDPE film/foam,", *Journal of Applied Polymer Science*, vol.135, no. 26, pp.46425, 2018.

[6] C. H., Huang, J. S., Wu, C. C., Huang, L. S. Lin, "Morphological, thermal, barrier and mechanical properties of LDPE/EVOH blends in extruded blown films", *Journal of Polymer Research*, vol.11, no. 1, pp.75-83, 2004.

[7] N.K., Kalfoglou, C.K., Samios, C.P. Papadopoulou, 'Compatibilization of poly (ethylene-co-vinyl alcohol) (EVOH) and EVOH–HDPE blends: Structure and properties', *Journal of applied polymer science*, vol.68, no. 4, pp.589-596, 1998.

[8] A. Saini, C. Yadav, M. Bera, P. Gupta, and P. K. Maji, "Maleic anhydride grafted linear low-density polyethylene/waste paper powder composites with superior mechanical behavior," *J. Appl. Polym. Sci*., vol. 134, no. 31, 2017.

[9] A. C. Chang, T. Inge, L. Tau, A. Hiltner, and E. Baer, "Tear strength of ductile polyolefin films," *Polym. Eng. Sci.*, vol. 42, no. 11, pp. 2202–2212, 2002

[10] C.-H. Huang, J.-S. Wu, C.-C. Huang, and L.-S. Lin, "Adhesion, permeability, and mechanical properties of multilayered blown films using maleated low-density polyethylene blends as adhesion-promoting layers," *Polym. J.*, vol. 35, no. 12, pp. 978–984, 2003

[11] F. Hosseinabadi, S. M. Zebarjad, and M. Mazinani, "Investigation on perforation mechanism of medium density polyethylene," *Mater. Sci. For*., vol. 675–677, pp. 387–390, 2011.

[12] ASTM F88/F88M-15, 2015, Standard test method for seal strength of flexible barrier materials.

[13] G. De Martino, L. Barnini, R. Pariante, & O. R. de Ballseteros, "Films with nine layers coextrusion technology, new challenge for food packaging" *Journal of Applied Packaging Research*, vol. 10, no. .2, p. 6, 2018.

[14] ASTM D2732-03. Unrestrained linear thermal shrinkage of plastic film and sheeting, 2024.

[15] L. Wang, "Effect of regrind content on PP-EVOH sheets properties and effect of orientation on permeability of EVOH multilayer films" Doctoral dissertation, Ecole Polytechnique, Montreal- Canada, 2019.

[16] Y. Liu, S. Wei, "Processing technologies of EVOH/nano-SiO_2 high-barrier packaging composites." *In Proc. 17th IAPRI World Conf. Packaging*, pp. 269-74. Tianjin: Scientific Research Publishing, 2010.