

Study of Mechanical Properties of Recycled Polyethylene of High and Low Density

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Abstract: *High and low density polyethylene materials constitute about 48% of total weight of plastics waste in Europe, that depends on the frequent use of these materials in packaging applications. This paper analyze the recycling effect on the mechanical properties of high and low density polyethylene (HDPE and LDPE). A mechanical recycling process was tested for the plastics waste of high and low density polyethylene, then a tensile and impact tests were performed on different mixing ratios for each of the both materials ranging from 100% of the virgin material and up to 100% of the recycled material with a difference of 10% of the sample to the other. This paper discusses the tensile properties of tensile stress at the fracture, elongation and modulus of elasticity and the impact test results for HDPE and LDPE were compared with each other.*

Keywords: *mechanical recycling, high density polyethylene, low density polyethylene, plastics waste*

1. Introduction

Plastic packaging waste consists almost half of the waste in Russians waste composites during 2020, for both of high and low density polyethylene, which represent the largest ratio about (48%) of plastic waste overall and being intended for landfill deposits, they are either incinerated in the open air, which leads to toxic gases and dioxides discharge, or disposed in an unsafe way, which means that they buried in the soil over hundreds of years is quite enough for their degradation [1-5], which leads to environmental problems in soil, water and even air pollution and causes serious damage to human health, although this waste could still serve as a source of raw materials [6-10].

The solution of plastic packaging waste problem in many cases can be realized by their mechanical or chemical processing. In the developed countries, the mechanical processing has found wider applications as it is more efficient because it consumes less energy [11-15].

Therefore, in this study, a mechanical treatment process was carried out, which consists of sorting, washing and granulating high (HDPE) and low (LDPE) density materials. Tensile and shock resistance test procedure was performed at various ratios of mixing recycled and pure materials to study the effect of the recycling process on mechanical properties of the aforementioned polyethylene materials and to discover the effectiveness of recycling to receive granules with good mechanical properties compared to the pure materials.

2. Materials and methods

The tested materials were the following types of polyethylene:

- high density polyethylene (HDPE) in two forms of recycled granules (R) made of waste containers for cleaning agents, shampoo and milk bottles, and pure granules (V) for their production;
- low density polyethylene (LDPE) in two forms of recycled granules (R) made of the remains of bottle caps and containers from some types of bottles, and pure granules (V) for their production.

The mechanical recycling process for these two test plastic waste materials was started with separating high density and low density polyethylene from other waste, cutting, washing and drying them, and then granulating to obtain recycled granules from both types of material.

Samples for testing were formed using a laboratory molding press and special shapes.

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Straight reference samples for tensile and shock resistance were manufactured in accordance with international standards: tensile test samples - in accordance with ISO 527 (4A), and samples for shock resistance (Charpy test) - in accordance with ISO 179 Model 51D, whereby two materials (high density polyethylene and low density polyethylene) were molded at 190°C temperature, 430 bar discharge pressure, room temperature (23+ -2°C) and relative humidity (50 + -5%) in accordance with ISO 294 international standards.

3. Results and discussions

Results of tensile tests:

Table (1) shows tensile properties of (HDPE) and (LDPE) samples for various ratios of mixing pure materials (V) and recycled materials (R).

Table 1. Mechanical properties of (HDPE) and (LDPE) samples under tension

Mixing ratio %	Stress, MPa		Relative elongation %		Flexibility factor MPa	
	HDPE	LDPE	HDPE	LDPE	HDPE	LDPE
100% V	27.55	9.24	113.64	55.08	24.7	17.47
90% V, 10% R	27.66	9.57	199.58	72.72	25.75	17.87
80% V, 20% R	20.66	7.55	53.34	58.46	43.70	17.98
70% V, 30% R	19.15	7.19	37.43	43.02	60.78	17.90
60% V, 40% R	17.87	7.08	36.18	41.47	66.81	21.51
50% V, 50% R	17.00	5.46	31.68	40.56	72.09	20.90
40% V, 60% R	16.15	9.63	31.79	40.44	72.20	20.21
30% V, 70% R	23.31	9.67	31.86	40.37	73.06	19.55
20% V, 80% R	24.87	9.88	31.93	39.91	78.30	62.23
10% V, 90% R	25.00	9.98	24.08	40.26	88.42	33.42
100% R	26.44	9.01	21.71	51.59	209.76	17.30

The results of tension tests of (HDPE) samples show an increase in tensile stress of a sample consisting of recycled materials for 10% and of pure materials for 90% (27.55 MPa) (Figure 1), while tensile stresses decrease as the percentage of recycled materials (HDPE) increases by more than 10% in the mixture until it reaches 60%, and then the stress values increase until the sample is 100% recycled materials (HDPE).

The results obtained in the course of tensile tests of samples made of (LDPE) show an increase in tensile stress of a sample consisting of recycled materials for 10% and of pure materials for 90% (9.57 MPa), and a decrease in values of this stress as a percentage of the amount of recycled materials (LDPE) increased by more than 10% in the mixture until its ratio reached 50%, and then tensile stress values increase after this percentage, but changes are in a limited range (9.01-9.98 MPa) (Figure 1).

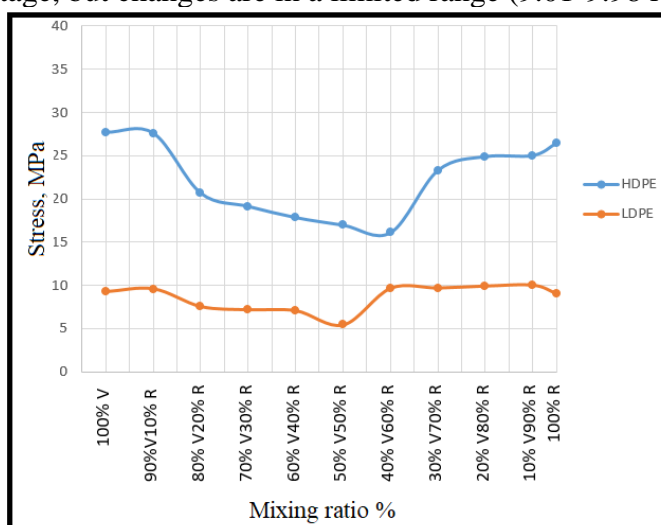


Figure 1. Tensile stress diagram for (HDPE) and (LDPE) samples

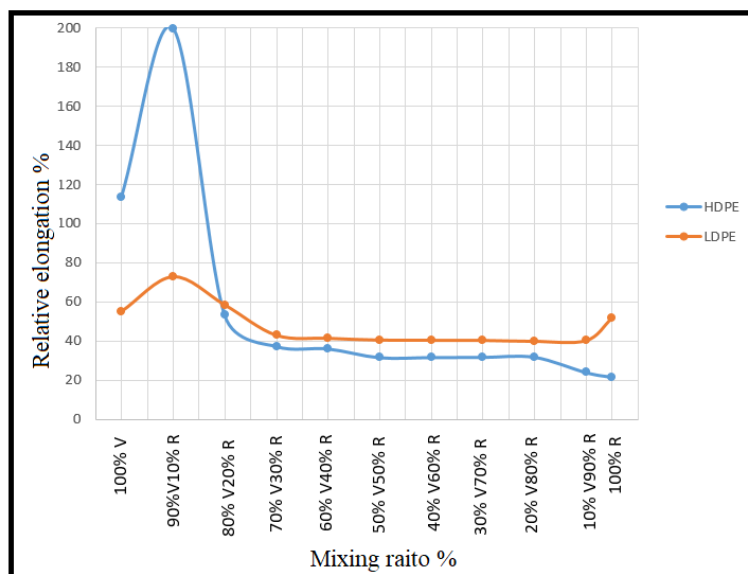


Figure 2. Elongation diagram of (HDPE) and (LDPE) samples

The results of flexibility factor LDPE measurement indicate that an increase of the recycled materials percentage in the mixture leads to an increase in the flexibility factor value to the maximum value (209.76 MPa) when a sample is 100% recycled material and for LDPE flexibility factor, the results show a flexibility increase with an increase in the percentage of recycled materials in the mixture until its percentage reaches 80%, and then it decreases with an increase in the percentage of recycled materials above 80% in mixture, but despite the decrease in the flexibility factor value, when a 100% recycled material sample is tested, a value of 17.30 (MPa) is obtained, which is very similar to the value of the sample consisting of 100% pure materials (17.47 MPa) (Figure 3).

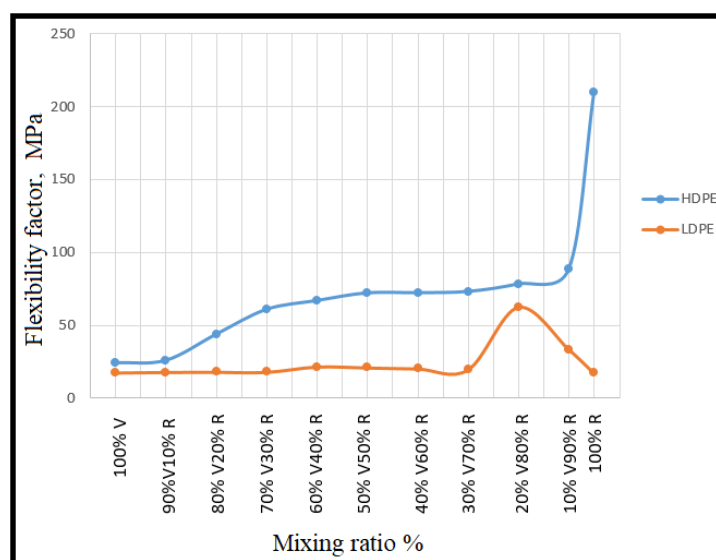


Figure 3. Flexibility factor diagram for (HDPE) and (LDPE) samples

The results of flexibility factor measurement (LDPE) show that with increase of the percentage of recycled materials in the mixture a flexibility factor value increases up to the maximum value (209.76 MPa) when a sample is 100% recycled material (Figure 3).

As far as (LDPE) flexibility factor is concerned, the results show an increase in the flexibility factor of the material with an increase in the percentage of recycled materials in the mixture until its percentage reaches 80%, and then it decreases with an increase in the percentage of recycled materials above 80%

in mixture, but despite the decrease in the flexibility factor value, when a sample is 100% recycled material takes on a value very close to 17.30 (MPa) than its value when a sample is 100% pure material (17.47 MPa) (Figure 3).

3.1. Impact test results

Table (2) shows the results of Charpy impact test for both (HDPE) and (LDPE) samples at various mixing ratios of pure (V) and recycled materials (R).

Table 2. Results of Charpy impact test for (HDPE) and (LDPE) samples at various mixing ratios

Mixing ratio %	Shock resistance KJ/m ²	
	HDPE	LDPE
100% V	137.5	125
90% V, 10% R	145	125
80% V, 20% R	145	127.5
70% V, 30% R	150	131.5
60% V, 40% R	160	135
50% V, 50% R	170	150
40% V, 60% R	175	155
30% V, 70% R	180	137
20% V, 80% R	177.5	137.2
10% V, 90% R	175	137.5
100% R	167.5	140

The impact test results of samples, made from the studied materials (HDPE and LDPE), were improved with an increase in the recycled materials proportion in the mixture (Figure 4). The mechanical characteristics improvement is explained by the addition of waste material in higher percentage to the mixture, because different content of polymer hardness elements in the processed mixture, the strain hardening presence and the condensation in these materials ultimately lead to the strengthening of the final product and to an increase in its resistance.

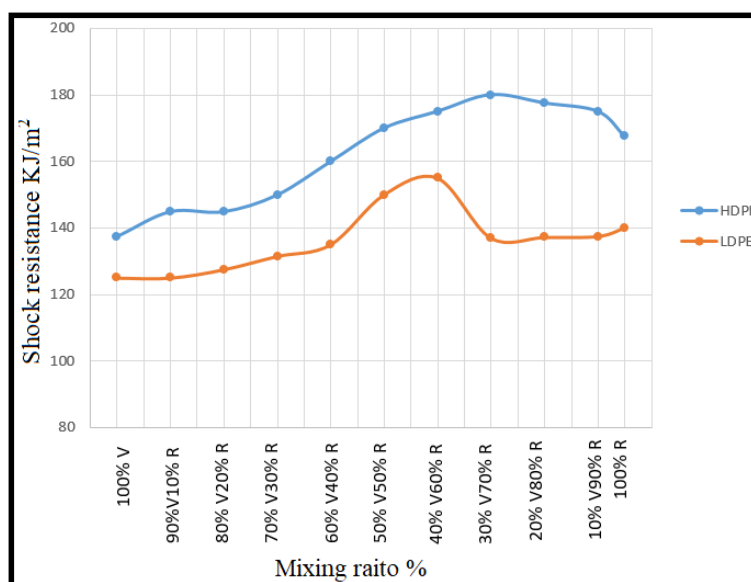


Figure 4. Impact test diagram of (HDPE) and (LDPE) samples

4. Conclusions

No irregularities were noticed in the mechanical characteristics of the samples taken at different mixing ratios, therefore there is a possibility to use recycled materials in various spheres, which indicates the importance of investment and the need to recycle plastic waste.



It can be noted that tensile properties of mixed material (90% (V) and 10% (R)) are better than those of pure materials.

An obvious improvement in tensile stress for polyethylene samples should be noted when mixing a higher proportion of recycled materials, as values of tensile stresses are better for samples consisting of recycled materials for more than 60% (HDPE) and 50% (LDPE). Thus, it is possible to manufacture products with good mechanical properties, consisting of 100% (R) polyethylene materials of both high and low density; it can be explained by improvement in mechanical characteristics when adding more recycled material to the mixture, strengthening these materials, and condensation of crystals with each other. Some of them are the result of this reactive stiffness, in addition to the presence of polymer elements of varying hardness in the recycled mixture; it results in hardening of end material and an increase in its resistance and thus improvement of its properties, which is consistent with the results published in scientific references [6-7].

It should be noted that there is a decrease in a elongation value of mixed materials with an increase in the percentage of recycled materials by more than 10% in the mixture for each of two studied materials.

A high value of flexibility factor of the samples made of (HDPE) can be noted, which is compensated by stability of the flexibility factor for (LDPE) to some extent.

An increase in resistance of the mixture with respect to two types of materials with an increase in the percentage of recycled materials in the mixture can be noted.

Based on the results of experiments, it can be noted that a scaling relation can be obtained, which can be used for recycled materials according to the intended use of the product, for example, if a plastic product is subjected to dynamic loads, the percentage of recycled materials in the plastic mixture can be increased and thus the Charpy impact rate of the product is improved.

Based on the above and due to economic terms, there is a possibility to apply recycled plastic granules as raw materials for their use in various industries (since they have good mechanical properties) is found, which plays an important role in cost-effective manufacturing of products when mixed with pure materials or in manufacturing of products made of recycled granules for 100%, which leads to enhancement of economic efficiency.

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Manuscript received: 20.09.2021