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THE EFFECTS OF HIGH DENSITY POLYETHYLENE ADDITION TO LOW DENSITY POLYETHYLENE POLYMER ON MECHANICAL, IMPACT AND PHYSICAL PROPERTIES

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Polyethylene materials are the most widely used polymers which we encountered everywhere in our daily life. Some of the advantages of the polyethylenes are the diversity of production types, corrosion resistance, electrical insulation and recyclability. The main production methods are compression molding, transfer molding, rotational molding, injection molding, gas-assisted injection molding, extrusion and blown film extrusion techniques. It is possible to increase the mechanical properties of low density polyethylene materials by addition of high density polyethylene materials. Both polymer has same monomers but their chemical structure and bonding properties are different. Their physical properties can change with their chemical structure and bonding properties. In this study, 25%, 50% and 75% by weight of high density polyethylene were added to low density polyethylene. Granules were pre-mixed with a mechanical mixer before production of the samples. Plastic injection molding machine was used for specimen preparation. Density, hardness, tensile test, three-point bend test, compression test, tear test and Izod impact tests were performed. Densities and hardness values of the polymer blends decrease by the increasing amount of low density polyethylene. In general, it was observed that the mechanical properties of the polymer blends increase as the high density polyethylene content increase.

Key words*: Low density polyethylene, High density polyethylene, Density, Hardness, Tensile test, Three point bend test, Compression test, Tear test, Izod impact test*

1. Introduction

Polymeric metarials, light weight, cheapness, insulation, sufficient mechanical properties, easy formability, decorative and ergonomic usage, chemically resistant and can be used for different purposes. Due to these properties, it has wide usage fields such as machinery, chemistry, physics, textile, industry, medicine, biochemistry and biophysics. Polymer as a word which derives from the origin of poly means multiple and mer(meros) means structure from two Greek words. Polymers consist of monomers. Monomers are the structures that can be connected to each other by covalent bonds to form large molecules. The production methods of polymers includes first the polymerisation of polymer as a

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chemical process, after producing the desired part with mechanical and thermal process. Thermoplastic materials are in the subgroup of polymers and can be finalized by being shaped by heat and mechanical treatment. These process can be performed again and again on these materials. But their physical properties can change against heat, remolding and forming process. Injection molding, gas-assisted injection molding, extrusion, blown film extrusion, rotational molding, pressure molding and transfer molding are the main production methods of thermoplastic polymer products [1, 2]. Polyethylene is a polymer with a broad range application areas in plastics industry. Polyethylene is a group in polyolefin family. Its chemical structure includes methylene (CH_2) monomers. Polyethylene materials are classified according to their density and bonding type. Low density polyethylene (LDPE), linear bonded low density polyethylene (LLDPE), medium density polyethylene (MDPE), high density polyethylene (HDPE), ultra high molecular weight polyethylene (UHMWPE) and cross-linked polyethylene (XLPE) are the six different types of polyethylenes. Some of the wide range application areas of polyethylenes are chemical containers, detergent cups, tubes, pressurized water and gas pipes, cable insulation, some automotive parts, various food storage containers, shopping bags, pochette and plastic bags, entertainment and toys. HDPE and LDPE are the most widely used polyethylene types. Both thermoplastics are suitable for injection and extrusion productions.

Polymer blends which have called as polymer alloys have been performed by researchers with mixing different polymers from many years. Productions and physical tests of HDPE-polypropylene (PP), HDPE-LLDPE and LDPE-polyamide 6 (PA6)-ethylene vinyl acetate (EVA) alloys were carried out [4]. Shebani et al. 2018 added 20%, 40%, 60%, and 80% LDPE polymer to the HDPE polymer. They performed tensile test, charpy impact test, hardness measurement and differential scanning calorimeter (DSC) tests. They found out that with the addition of LDPE, tensile strength and hardness values decreased, but the elongation at break and the toughness values increased [5]. Sarkhel et al. 2006, in their study, HDPE blended LDPE in 80/20, 60/40, 40/60 and 20/80 ratios respectively to obtain polymer mixtures. They found that the melt viscosity of these mixtures decreases with the increased concentration of LDPE. Besides, they found out that increased amount of LDPE causes the deterioration in mechanical properties from the results of tensile tests. However they determined that the increasing amount of LDPE in mixture, increased the Izod impact strength values. As a result, they observed that as the LDPE ratio in HDPE polymer increased, the crystal ratio decreased in DSC analysis [6, 7].

In this study, 25%, 50% and 75% by mass of HDPE polymer was added to LDPE polymer. Density, hardness, Izod impact, tear, tensile, three point bending and compression tests were performed.

2. Material and Method

2.1. Materials

Two different polymer were mixed in different ratios in this study. A new polymer alloy was produced by mixing these two different polymers. LDPE polymer was used as a granular form Petilen I22-19T commercial product with a melt flow rate of 22 g/10 min (190 °C / 2.16 kg) of PETKIM. HDPE polymer was used as a granular form Petilen I668 commercial product with a melt flow rate of 5.5 g/10 min (190 °C / 2.16 kg) from PETKIM. Both polymers are suitable for injection molding.

2.2. Preparation of Samples

The production of LDPE-HDPE mixtures, granular materials were pre-mixed with Heidolph brand, RZR 2021 model mechanical mixer. 25%, 50% and 75% by mass of HDPE was added to the

LDPE polymer. Each formula was mixed at 200 rpm for 10 minutes. The samples were dried in the oven at 60 °C for 4 hours to remove moisture. Specimens were prepared in a single screw plastic injection molding machine (diameter: 35 mm, L/D ratio: 30, clamping force: 700 kN). Mixtures were injected into mold at 170-180-190-200 °C temperatures from feeding zone to nozzle zone. Mechanical mixer, oven and plastic injection molding machine are shown in Figure 1.

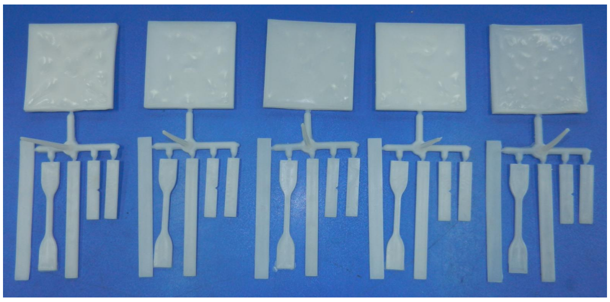
(a) (b) (c)

Figure 1. Equipment and machines used in production a) mechanical mixer, b) oven and c) plastic injection machine

Mixing ratios by weight of the samples are given in Table 1. Thirty specimen groups were produced from each formulas. The specimen group includes tensile test, flexural test, tear test, conical calorimeter test, compression test, notched and unnotched Izod impact test specimens (Figure 2).

Table 1. Mixing ratios of HDPE-LDPE blends

Specimen	Code	LDPE (%)	HDPE (%)	Total (%)
LDPE	LDPE	100	-	100
LDPE3-HDPE1	L3H1	75	25	100
LDPE1-HDPE1	L1H1	50	50	100
LDPE1-HDPE3	L1H3	25	75	100
HDPE	HDPE	-	100	100



HDPE L1H3 L1H1 L3H1 LDPE

Figure 2. The produced samples in the plastic injection molding machine

2.3. Tests and Characterizations

All samples were stored in Nüve brand TK252 model conditioning cabinet at 23 °C and 50% relative humidity for 40 hours according to ASTM D618 standard before tests (Figure 3). Tests were performed at 23 °C and 50% relative humidity.

Figure 3. Nüve TK 252 conditioning unit

The density measurement was made from 6 samples from each formulas. The mass and volumes were measured and the density of the samples were calculated by dividing the mass by volume according to ASTM D792 standard. Three-point bending samples were used for density measurement (Figure 4). Hardness measurements were carried out on 6 samples in X.F Shore-D hardness tester (Figure 5) according to ASTM D2240 standard.

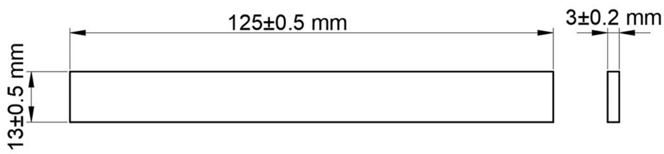


Figure 4. The dimensions of three-point bending specimen [3]

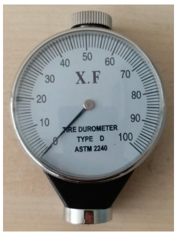
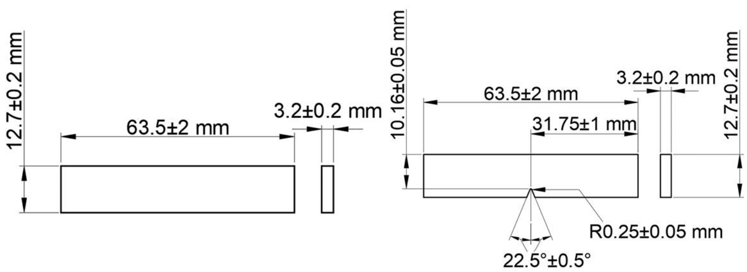


Figure 5. X.F Shore-D durometer

Impact strength properties were determined with pendulum impact test machine. Izod impact resistance test was performed at Ceast Resil Impactor device (Figure 6) according to ASTM D256 standard. 6 samples were tested from each mixture with 7.5 J to 25 J. The dimensions of the specimens are shown in Figure 7. The size of notch is 2.54 mm depth with an angle of 45° according to ASTM D256 standard.

Figure 6. Ceast Resil impactor test device [3]



(a) (b)

Figure 7. The dimensions of Izod impact test specimens (a) unnotched and (b) notched [3]

Tear strength test was performed on 6 samples from each mixture according to ASTM D624 (Type-T) standard. The tests were performed on Shimadzu brand AGS-X 100 kN model 100 kN load cell equipped static tensile-compression tester (Figure 8) with a tensile speed of 50±5 mm/min. The dimensions of the tear test specimens were given in Figure 9. Tear strengths of mixtures were calculated from tear tests.

Figure 8. Shimadzu AGS-X 100 kN tensile-compression test device

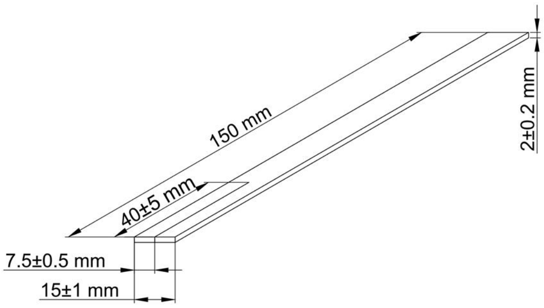


Figure 9. The dimensions of tear test specimen [3]

Tensile tests were performed in Shimadzu brand AGS-X 100 kN model 100 kN load cell equipped static tensile-compression test device at 50 ± 5 mm / min tensile speed according to ASTM D638 (Type-IV) standard. The dimensions of the tensile test specimens are given in Figure 10. Six tensile test specimen were tested from each formulas. Tensile strength, rupture strength, modulus of elasticity according to tensile condition, elongation at break and toughness values of the material were calculated from the tensile tests.

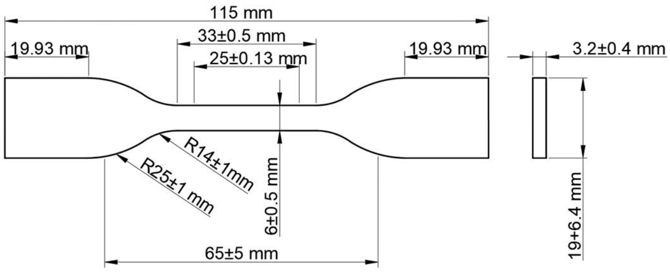


Figure 10. The dimensions of tensile test specimen [3]

Three-point bend tests were performed in Instron 8801 model 50 kN load capacity dynamic tensile and compression test device according to ASTM D790 standard with crosshead speed of 1.4564 mm/min (Figure 11). The sizes of the three point bend test specimen is given in Figure 4 and six specimen were tested from each formula. Bending strength and flexural modulus according to bending condition values were calculated from the tests. 5% strain were taken into account to find the flexural strength values.

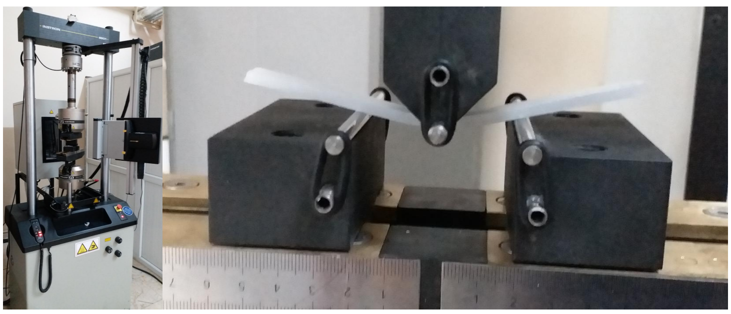


Figure 11. Instron 8801 dynamic tensile-compression test device

Compressive tests were performed in Shimadzu brand AGS-X 100 kN model 100 kN load cell equipped static tensile testing machine was used with crosshead speed at 1.3 mm/min according to ASTM D695 standard. The compressive test plates were shown in Figure 8. The sizes of the compression test specimen less than 3.2 mm thickness is given in Figure 12 and six specimen were tested from each formulas. Compressive strength, yield stress in compression and compressive modulus values were calculated according to the compression state. 10% deformation values were taken into account of the specimens for compressive strength values. The compressive modulus of HDPE and LDPE were calculated from the slope of the linear region in stress-strain curve.

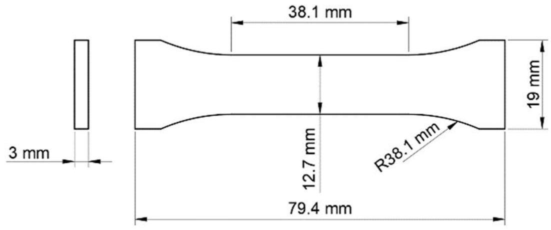


Figure 12. The dimensions of compressive test specimen

3. Experimental Results and Discussion

3.1. Density

The results of the density measurements; mean values, maximum and minimum ranges were given in Figure 13(a). The mean and standard deviation of the density values were given in Table 2. The addition of LDPE to the HDPE polymer increase the density values. The density of pure LDPE was 0.888 g/cm^3 while the density of pure HDPE was 0.951 g/cm^3. The addition of 25% mass of HDPE to LDPE polymer increases the density by 2% to 0.905 g/cm^3. Increasing amount of HDPE addition to LDPE polymer 50% and %75 mass increases the density by %3 and %4 to 0.913 g/cm^3 and 0.922 g/cm^3 respectively.

3.2. Hardness

Hardness value of the polymers plays key role in their usage areas. The meaning of the hardness is resistance of a material to deformation, indentation, penetration and scratching. The hardness values of polymers vary depending on their crystal phases. HDPE is more crystalline polymer (51%) than LDPE polymer (38%) [8]. The more crystalline phases bring more rigid and hard physical properties. [5]. This results are the evidence of this explanation. It has been observed that LDPE polymer hardness about 42.9 Shore-D and HDPE was 63.9 Shore-D in the hardness test. Figure 13(b) shows the average hardness values, the highest and the lowest ranges. Mean hardness and standard deviation values are given in Table 2. 25% mass of HDPE addition significantly increase the hardness values of LDPE by 34% to 57.4 Shore-D. %50 mass of HDPE addition increase the hardness values of HDPE by 35% to 57.9 Shore-D. Further addition of 75% mass of HDPE to LDPE polymer increase the hardness values by 44% to 61.6 Shore-D. The hardness value of the LDPE polymer was much lower than HDPE polymer. It was observed that significant change in the hardness values by adding HDPE to LDPE polymer.

3.3. Izod Impact Test

In spite of hammer value reached 25 J, unnotched Izod impact specimens couldn't be broken. The hammer tilted the sample and passed the other side. In the notched Izod impact experiments, no breakage was observed 25% by mass of HDPE in LDPE polymer and pure LDPE. That's because of the soft and more flexible segments of LDPE in LDPE-HDPE blend. 25% LDPE and 50% LDPE were added to the specimens were broken with a 7.5 J hammer (Figure 13(c)). Due to HDPE more crystalline than LDPE polymer and more co-monomer decrease the crystal orientation. This disrupts the impact properties of the polymer [9]. The Izod impact strength of notched pure HDPE was found 8.5 kJ/m^2. The addition of 75% and 50% mass of HDPE to LDPE polymer decrease the Izod impact strength values compared to HDPE polymer by %11 and %20 to 7.6 kJ/m^2 and 6.8 kJ/m^2 respectively. Mean Izod impact strength values and standard deviation values are given in Table 2.

3.4. Tear Test

The highest and lowest ranges of tear strength values of the blends are given in Figure 13(d). Mean tear strength and standard deviation values are given in Table 2. The tear strength value of pure LDPE was found 45 N/mm and pure HDPE was found 132 N/mm. The addition of 25% HDPE by mass to LDPE polymer increase tear strength values by 16% to 52 N/mm compared to LDPE. It was observed by the addition of %75 HDPE to LDPE polymer increased by 28% to 57 N/mm. The addition of 50% HDPE by mass to the LDPE polymer decreased to the lowest tear strength value by 52% to 21 N/mm. In general, it has been observed that HDPE addition to LDPE polymer increase the tear strength values. In contrast to this the addition of LDPE to HDPE polymer decreases the tear strength values remarkable except the addition of both polymer 50% weight percentage significantly decreases the tear strength values. Because of the branching network of LDPE more complicated than HDPE polymer [5-9]. This detoriates the tearing properties.

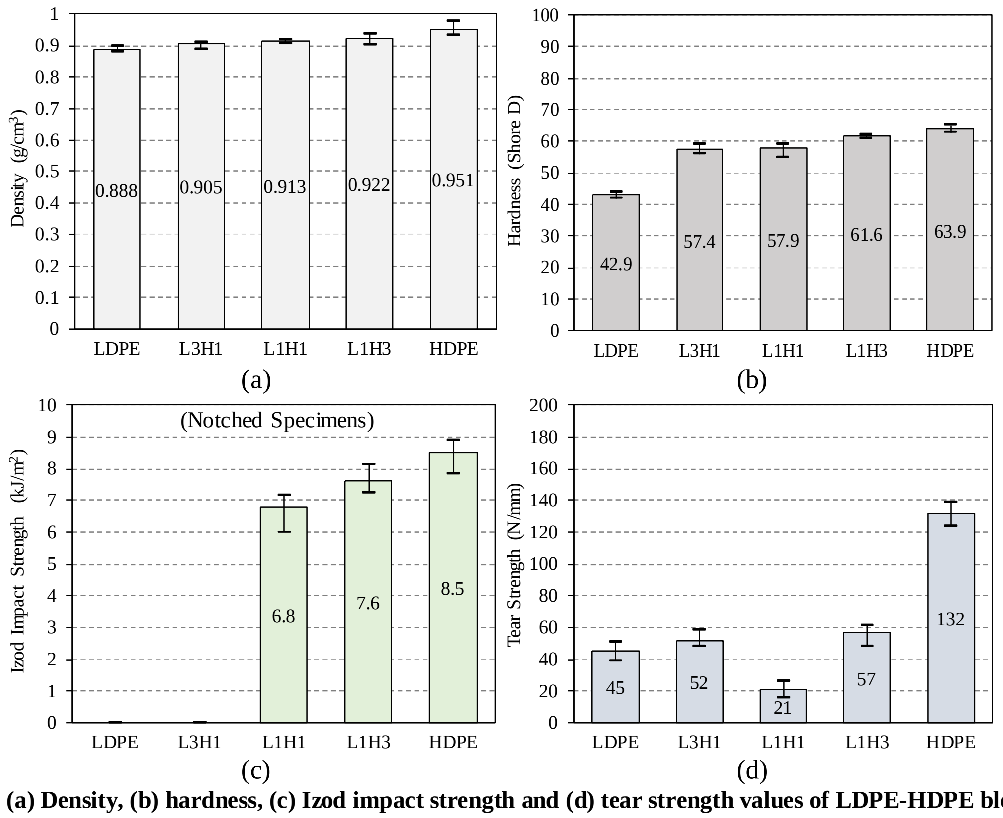


Figure 13. (a) Density, (b) hardness, (c) Izod impact strength and (d) tear strength values of LDPE-HDPE blends

Table 2. Density, hardness, Izod impact strength and tear strength values of LDPE-HDPE blends

Code	Density (g/cm³)	Hardness (Shore D)	Izod Impact Strength (kJ/m²)		Tear Strength (N/mm)
			Unnotched	Notched	
LDPE	0.888±0.007	42.9±0.8	-	-	45±5
L3H1	0.905±0.008	57.4±1.1	-	-	52±4
L1H1	0.913±0.004	57.9±1.7	-	6.8±0.5	21±5
L1H3	0.922±0.014	61.6±0.5	-	7.6±0.4	57±7
HDPE	0.951±0.016	63.9±0.9	-	8.5±0.4	132±7

3.5. Tensile Test

Tensile test is important to characterize the material mechanical behaviors from the stress-strain curves under tension state. This test was revealed to find suitable application and optimum usage ratio of LDPE and HDPE polymer blends. The tensile test curves of the LDPE-HDPE samples were given in Figure 14. Mean values and standard deviation values of tensile strength, rupture strength, modulus of elasticity, elongation at break and toughness values of the composites were given in Table 3.

The average, highest and lowest range values of tensile strengths were shown in Figure 15(a). It was observed that the tensile strength of LDPE polymer was found 7.7 MPa and HDPE polymer was 30.6 MPa. The addition of 25% mass of HDPE to LDPE polymer increases the tensile strength by 121% to 17 MPa. Furthermore, it was seen that 50% and 75% addition of HDPE to LDPE polymer decreases tensile strength by 142% and 213% to 18.6 MPa and 24.1 MPa values respectively.

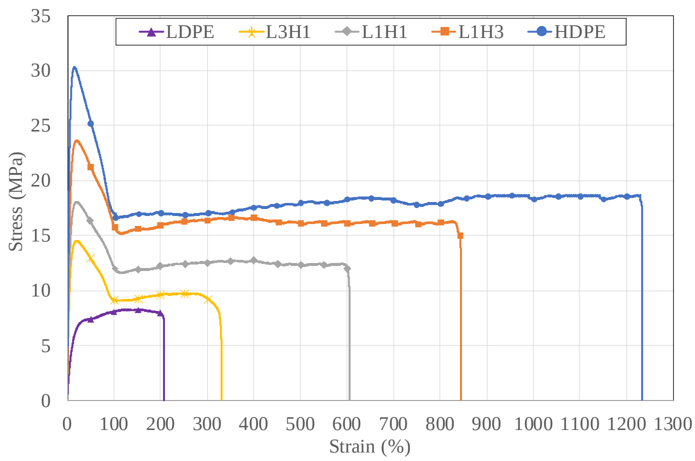


Figure 14. Stress-Strain curves of LDPE-HDPE blends

Table 3. Tensile test results of LDPE-HDPE blends

Code	Tensile Strength (MPa)	Rupture Strength (MPa)	Elasticity Modulus (MPa)	Elongation at Break (%)	Thoughness (J/mm³)
LDPE	7.7±0.4	7.1±0.3	102±12	208±12	1.6±0.2
L3H1	17±1.5	8.7±0.6	305±20	346±28	3.3±0.4
L1H1	18.6±0.6	12.5±0.3	448±38	670±40	6.9±0.6
L1H3	24.1±1.1	14.8±0.7	523±31	878±57	10.1±0.6
HDPE	30.6±1.3	17.7±0.6	920±46	1249±42	23.1±1.2

Same manner was observed in rupture strengths, the addition of HDPE to LDPE polymer were significantly increased the rupture strengths (Figure 15(b)). It has been determined that the rupture strength of LDPE was 7.1 MPa and HDPE was 17.7 MPa. The addition of HDPE by 25% mass to LDPE polymer increased the rupture strength by 23% to 8.7 MPa. 50% and 75% mass of HDPE addition to LDPE polymer were increased this value by 76% and 108% to 12.5 MPa and 14.8 MPa values respectively.

The elasticity modulus of LDPE and HDPE polymer were observed 102 MPa and 920 MPa respectively. 25% addition of HDPE to LDPE polymer was increased the elasticity modulus significantly by 199% to 305 MPa. It was observed that 50% of HDPE addition to LDPE polymer was increased by 339% to 448 MPa. Furthermore, the addition of 75% HDPE to LDPE polymer increased the elasticity modulus by 413% to 523 MPa (Figure 15(c)).

The elongation at break values of LDPE polymer was around 208%, while the elongation at break of HDPE polymer was 1249% (Figure 15(d)). By the addition of 25% HDPE to LDPE polymer, this value was seen to increase by 66% to 346%. The addition of 50% and 75% HDPE to LDPE polymer increased the elongation at break values by 222% and 322% to 670% and 878% respectively.

The thoughness values were observed from the tensile test curves. The areas under curves were calculated. The highest and the lowest ranges and mean values were given in Figure 15(e). Pure LDPE polymer thoughness value was calculated 1.6 J/mm^3 and HDPE polymer was 23.1 J/mm^3. It was observed that the addition of 25% mass of HDPE to LDPE polymer increase by 106% to 3.3 J/mm^3, 50% of HDPE to LDPE increases by 331% to 6.9 J/mm^3 and 75% of HDPE to LDPE increase by 531% to 10.1 J/mm^3.

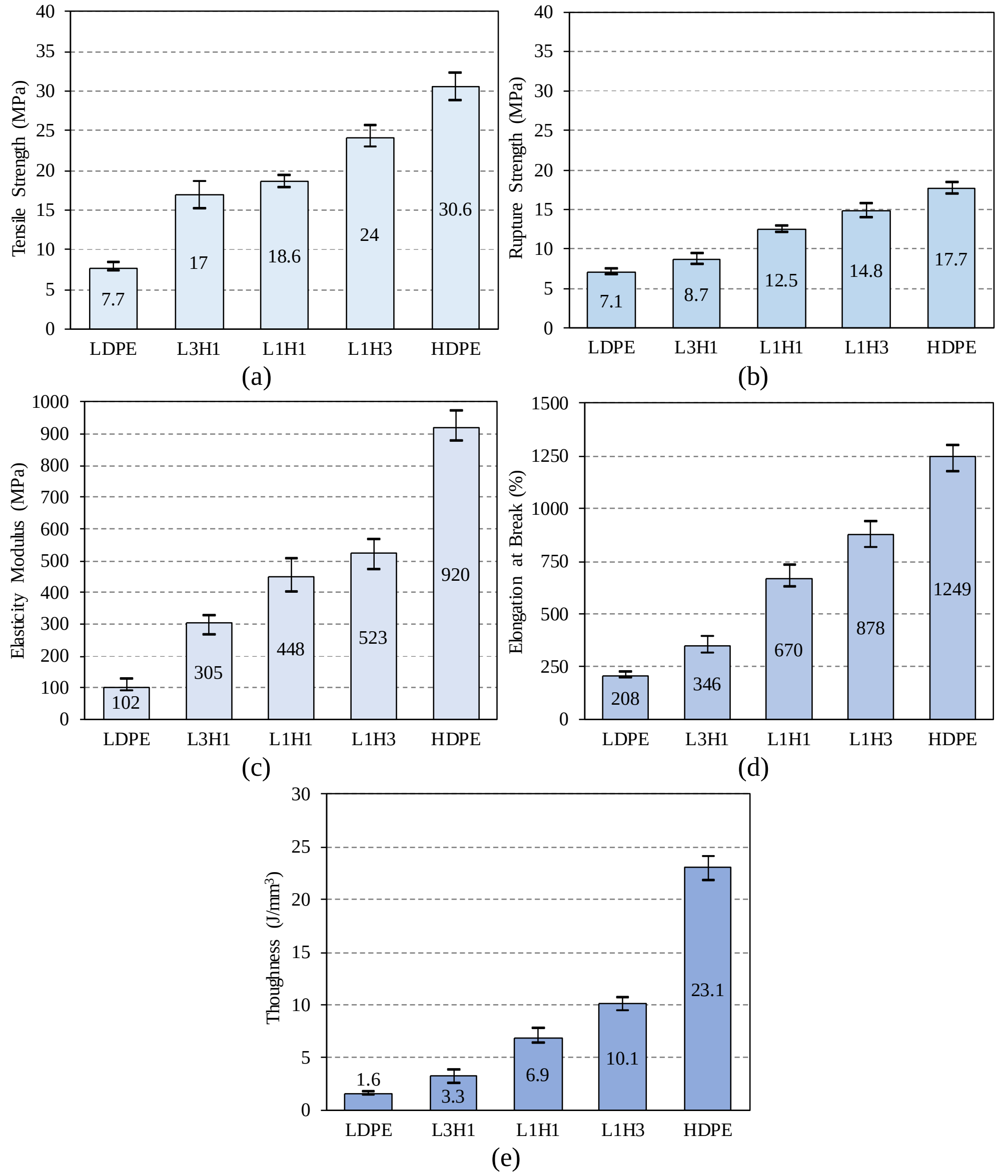


Figure 15. (a) Tensile strength, (b) rupture strength, (c) elasticity modulus, (d) elongation at break and (e) thoughness values of LDPE-HDPE blends

3.6. Three Point Bend Test

The mean and standard deviation values of flexural strength and flexural modulus of composites were given in Table 4. The addition of HDPE to LDPE polymer increased the flexural strength and flexural modulus values according to bending state.

Table 4. Three point bend test results of LDPE-HDPE blends

Code	Flexural Strength (MPa)	Flexural Modulus (MPa)
LDPE	7.8±0.5	345±19
L3H1	10.9±0.7	455±34
L1H1	13.3±0.8	558±29
L1H3	17.1±1.2	875±28
HDPE	24.3±0.9	1109±51

The average, highest and lowest range values of flexural strengths are shown in Figure 16(a). The flexural strength value of LDPE polymer was observed 7.8 MPa and HDPE polymer was 24.3 MPa. 25% by mass of HDPE addition to LDPE polymer was increased flexural strength value by 40% to 10.9 MPa. By mass of 50% and 75% additon of HDPE to LDPE polymer increased flexural strength by 71% and 119% to 13.3 and 17.1 MPa respectively.

The flexural modulus of LDPE polymer was calculated 345 MPa and HDPE polymer was 1109 MPa. The addition 25% by mass of HDPE to LDPE polymer increased the flexural modulus by 50% to 455 MPa, 50% mass of HDPE addition increased by 97% to 558 MPa and 75% addition increased by 241% to 875 MPa (Figure 16(b)). It was found that increasing amount of HDPE addition to LDPE polymer were increased the flexural strength and flexural modulus.

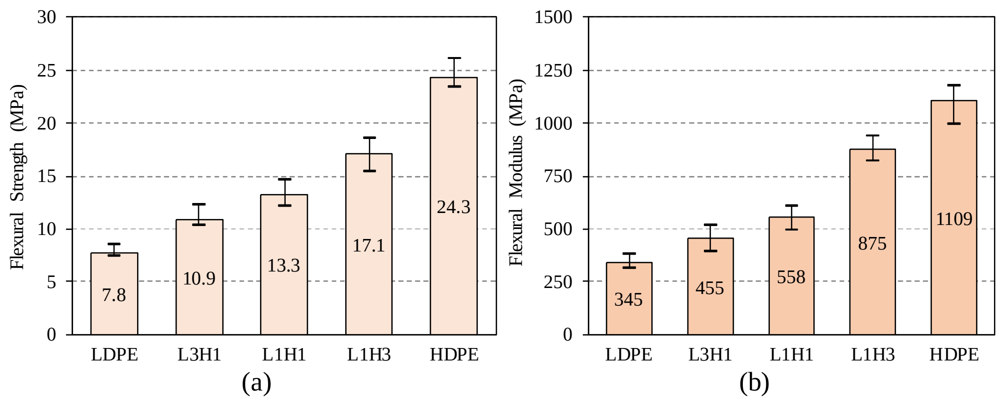


Figure 16. (a) Flexural strength and (b) flexural modulus values of LDPE-HDPE blends

3.7. Compressive Strength Test

Compressive strength, compressive yield strength and compressive modulus of LDPE-HDPE blends mean and standard deviation values were given in Table 5. The compressive strength value of LDPE was found 10.7 MPa and HDPE was 23 MPa. The addition of 25% HDPE to LDPE polymer was increased the compressive strength values of composite by 50% to 16.1 MPa. 50% and 75% addition of HDPE polymer to LDPE polymer were increased by 60% and 63% to 17.1 MPa and 17.4 MPa respectively (Figure 17(a)).

Compressive yield strength values of LDPE and HDPE were calculated 4.2 MPa and 9 MPa respectively. The addition of 25% HDPE to LDPE polymer increased by 126% to 9.5 MPa. 50% HDPE increased 76% to 7.4 MPa and 75% HDPE increased by 157% to 10.8 MPa (Figure 17(b)).

The highest and lowest ranges and mean values of compressive modulus were shown in Figure 17(c). The compressive modulus of LDPE and HDPE were found 185 MPa and 710 MPa respectively. Addition of 25% mass of HDPE to LDPE polymer increased the compressive modulus by 66% to 307 MPa. 50% HDPE addition increased by 107% to 383 MPa. Furthermore 75% addition of HDPE to LDPE polymer increased by %130 to 426 MPa.

Table 5. Compression test results of LDPE-HDPE blends

Code	Compressive Strength (MPa)	Compressive Yield Strength (MPa)	Compressive Modulus (MPa)
LDPE	10.7±0.7	4.2±0.4	185±12
L3H1	16.1±0.3	9.5±0.6	307±37
L1H1	17.1±0.7	7.4±0.5	383±36
L1H3	17.4±0.8	10.8±0.6	426±27
HDPE	23±0.8	9±0.3	710±40

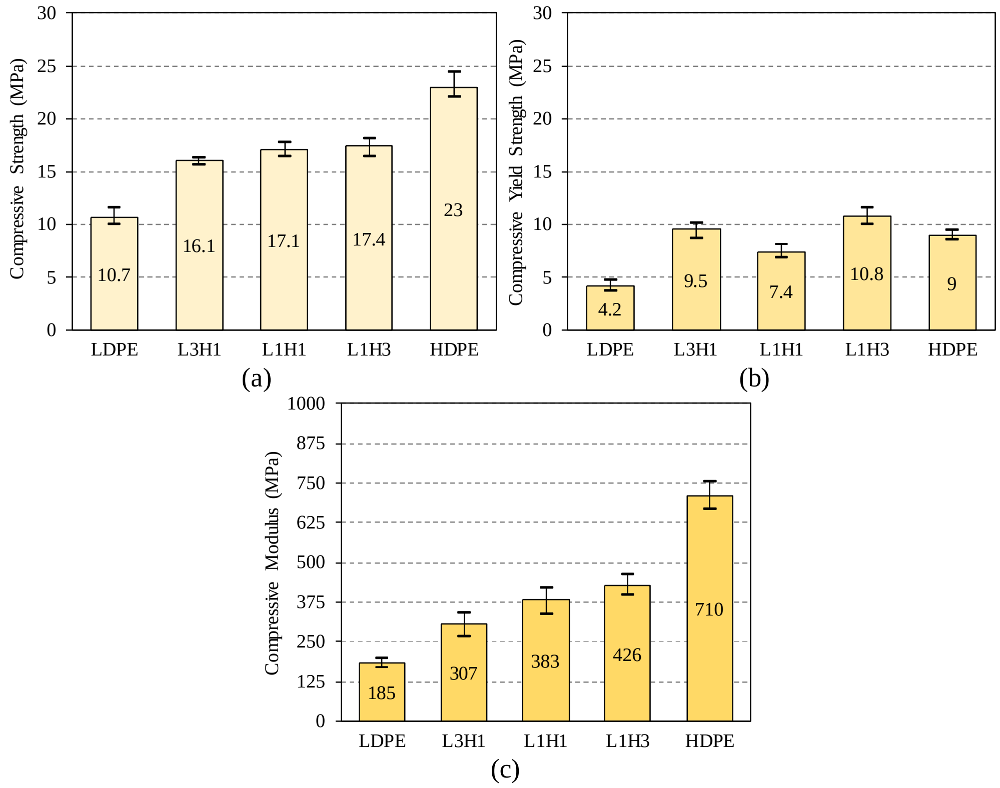


Figure 17. (a) Compressive strength, (b) compressive yield strength and (c) compressive modulus values of LDPE-HDPE blends

4. Conclusions

In this study, it was carried out that mixing the low density and high density polyethylene in different ratios. The production method of the samples were performed by plastic injection machine. HDPE polymers were added to LDPE polymers in 25%, 50%, 75% by mass and some physical and mechanical tests were performed. As a result of the studies, the following conclusions were drawn.

• It was found out that the addition of HDPE to LDPE polymer increase the density, hardness and tear strength values. In contrast, the addition of the LDPE to HDPE polymer decrease these values.

• In Izod impact tests, although the hammer energy increased to 25 J, all unnotched specimens couldn't be broken. HDPE, L1H3 and and L1H1 specimens were broken in notched Izod impact tests. The addition of 75% and 50% HDPE to LDPE polymer decrease the Izod impact strength values compared to pure HDPE polymer.

• It was found that the tensile curves obtained from the tensile test were in accordance with the pure LDPE and pure HDPE polymer tensile characteristics.

• Tensile strength, rupture strength, elongation at break, toughness and modulus of elasticity values were increased by adding HDPE to LDPE polymer from the results of the tensile tests.

• Flexural strength and flexural modulus values of the composites increased by the addition of HDPE polymer to LDPE polymer.

• It was observed that the addition of HDPE to LDPE polymer increases the compressive strength, compressive yield strength and compressive modulus. 25% and 75% of LDPE addition increase the compressive yield strength values above pure HDPE.

• In contrast to all results the addition of LDPE to HDPE polymer decreases the physical and mechanical properties of HDPE polymer.

• Thermal and combustion tests of these polymer blends will be performed in the next study.

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