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Mechanical and Thermal Properties of HDPE/LDPE Blends for Industrial Applications

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In this study, blends of high-density polyethylene (HDPE) and low-density polyethylene (LDPE) were comprehensively characterized to evaluate their suitability for industrial applications. Structural, mechanical, thermal, and surface analyses were performed to determine the influence of blend composition. The results showed that the 60/40 (HDPE/LDPE) blend exhibited superior mechanical performance, including tensile strength, impact resistance, and hardness, while the 80/20 blend demonstrated higher thermal stability and morphological uniformity. The results obtained demonstrate the potential for using HDPE/LDPE blends in many areas, including packaging, insulation, and engineering products that require a balance between durability and thermal stability. They also suggest their potential future application in agricultural irrigation pipes, which require highly reliable mechanical and thermal properties over the long term.

Keywords: HDPE, LDPE, SEM, Thermal, Mechanical, Contact angle

1 Introduction

One of the most popular systems in materials science is polymer composites. They have several uses[1-3]. Thermoplastic-thermoplastic blends, thermoplastic rubber blends, thermoplastic thermoset blends, rubber-thermoset blends, and polymer filler blends are the five fundamental types of polymer blends,all of which have been the focus of substantial research[4,5]. Among the most popular thermoplastics is polyethylene (PE). It is inexpensive, easily shaped, and produced in large quantities for a range of industrial uses. Low-density polyethylene (LDPE) and high-density polyethylene (HDPE). LDPE has molecular structure that proved excellent ductility and high flexibility. HDPE, on the other hand, has superior mechanical and thermal resistance, high hardness, and greater crystallinity[6-9]. The development of novel materials with enhanced qualities to satisfy the needs of diverse technical, agricultural, and industrial applications is made possible by the efficient blending of LDPE and HDPE, which strikes a balance between strength and flexibility. Prior research indicates that a higher LDPE content led to an increase in impact resistance and a decrease in hardness. Applications requiring great resilience to cracking and dynamic loads depend on this characteristics[10-13]. To comprehend these mixes' stability and internal structure, it is essential to investigate their thermal characteristics. Accurate information on melting points, decomposition rates, and crystallinity can be obtained using thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) methods[14,15]. The internal morphology and surface structure of alloys are revealed by the scanning electron microscope (SEM)[16]. The surface's wettability and liquid-interaction characteristics are reflected in the measurement of the contact angle. It is a crucial component in assessing how the material will behave and hold up over extended periods of use[17,18]. According to the, a crucial first step in assessing the potential of LDPE/HDPE blends for industrial application in a variety of sectors, including packaging materials, protective insulators, and irrigation pipes, is the thorough characterization of these blends employing mechanical, thermal, and structural testing. However, most previous studies have focused separately on either the mechanical or thermal properties of HDPE/LDPE blends, with limited comprehensive investigations that include surface characteristics[19, 20]. Therefore, this study aims to obtain the best mixture ratio that combines flexibility and durability to suit industrial applications, especially those such as irrigation pipes, packaging, and others.

2 Materials

The HDPE used in this work was obtained from Basra Petrochemical Company (grade 4710), while the LDPE was supplied by SABIC. The blends were prepared in three weight ratios: B0 (100% HDPE), B1

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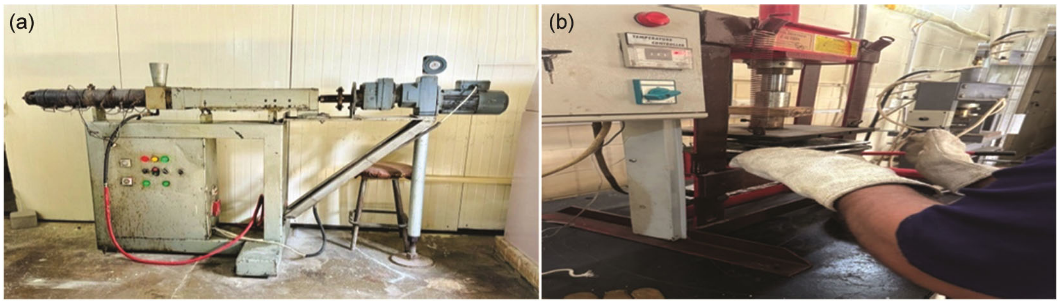

Fig. 1 — Schematic diagram of the extrusion and molding process used for preparing HDPE/LDPE blends

(60% HDPE + 40% LDPE), and B2 (80% HDPE + 20% LDPE). The polymer granules were dried, mixed, and processed using a twin-screw extruder followed by water quenching to obtain solid specimens Mechanical properties were evaluated according to international standards: hardness (ASTM D2240, Shore D), impact resistance (ISO 179, Charpy method), and tensile behavior (ASTM standard samples). The surface morphology was examined using a scanning electron microscope (SEM), while wettability was determined from contact angle measurements. Thermal stability was investigated using thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) with a Shimadzu Q600 analyzer. siemens.

2.1 Preparation of Polymer Blends

2.2.1 *Mixing and Extrusion Process*

To obtain the best distribution, the polymer granules of HDPE and LDPE were weighed and mixed according to the selected weight ratios. The mixing was carried out under dry conditions at room temperature. The forming process was carried out using a twin screw extruder model APV company / British origin, containing six heaters and rotating at a speed of (0-40 rpm). It is available at the Ministry of Higher Education/ Scientific Research Authority/ Materials Research Department/Baghdad. The extruder is heated to a temperature of 250°C. The piston is also heated to the same temperature as shown in Fig. 1. The pre-mixed polymer granules are fed from a screw-mounted chuck. These granules are then transferred to the heaters in sequence until they come out completely melted. They are placed in a mold measuring 100-150 ml and then directly transferred to a locally made heat press heated to 250°C under a pressure of 5 MPa for 15 minutes. After that, Then, place the mold in a static water bath at a temperature of 14-17°C for 15 minutes until it cools and becomes ready.

2.2 Characterization of HDPE /LDPE Composition

The scanning electron microscope examination was performed for the highest and lowest percentage of LDPE added to HDPE (B1, B2) is employed to examine the surface architecture of materials with high precision, as it yields detailed images that reveal cracks, porosity, and distribution, thereby facilitating the assessment of integration and homogeneity among polymers[21]. The ability of a substance to withstand scratches, dents, or deformation is known as its hardness. ASTM D2240 udometer (shore D) using three specimens for each composition (B0, B1,B2). The kind of forces holding its atoms and molecules together determines the hardness value. As the strength of the link and cohesiveness between materials grows, so does the hardness value[22]. Charpy impact tests were performed to determine the mechanical performance of impact strength utilizing impact testing according to the ISO-179 standard test technique, with dimensions of 5.5 cm × 1 cm by using three specimens (B0, B1,B2). The samples (B1, B2) were cut according to ASTM specifications for the device. The polymer blend samples weighed 3–5 mg and were heated at a rate of 10°C/min from 0-700°C. The thermogravimetric analyzer model Q600 Shimadzu was used to evaluate the thermal stability of the polymer blend and perform thermal gravimetric analysis (TGA). This technique measures the mass of a sample in relation to its temperature. Because it records temperature changes and establishes a material's melting and glass transition points, differential scanning calorimetry (DSC) is an appropriate test for examining a material's thermal behavior and phase transformations.

3 Results and Discussion

3.1 Scanning Electron Microscope (SEM)

Scanning electron microscope examination was performed for the highest and lowest percentage of

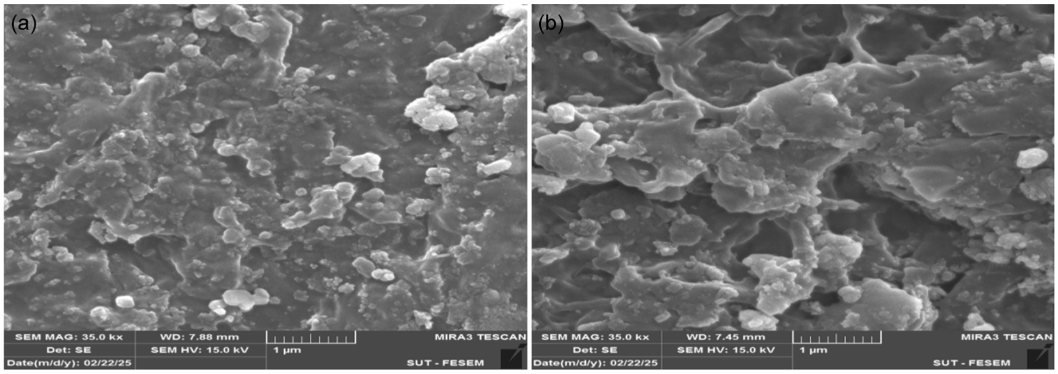

Fig. 2 — SEM micrographs of HDPE/LDPE blends B1 and B2 showing distinct surface phase morphology features

LDPE added to HDPE. Through the SEM image of sample B1 (60% HDPE + 40 % LDPE) as shown in Fig. 2 (a) the mixture was not perfectly homogenized, as there are two separate phases, one of which represents crystalline HDPE and the second represents amorphous LDPE. There are prominent aggregates and granules, reflecting partial phase separation, meaning the mixture is nearly homogeneous. This is because the mixing and extrusion took place in a very cold winter climate. The extruder temperature was not ideal, so the temperature needed to be raised further to ensure greater homogeneity between the two polymers. This morphology could explain the change in mechanical properties so that the hardness decreases, and the shock resistance improves because of the presence of soft areas distributed within the solid matrix[23]. In sample B2 (80%HDPE + 20% LDPE) shown in Fig. 2 (b) it was found that the surface structure became rougher and harder as a result of the dominance of the crystalline phase of HDPE. At the same time, the LDPE appeared in the form of small clusters or nodules distributed within the matrix. That is, it is a partial mixture. This morphology is reflected in the mechanical properties, as it increases the hardness and reduces the elasticity compared to sample B1. The shock resistance remains acceptable due to the presence of the second phase regions that help absorb part of the stress[24].

3.2 Hardness Behavior of HDPE/LDPE Blend

Figure 3 show the hardness results of the HDPE/LDPE blends (B0, B1, and B2) showed a clear dependence on composition. Sample B1 (60% HDPE / 40% LDPE) exhibited the highest Shore D hardness value (69.7), which can be attributed to improved structural distribution and a balanced combination of rigidity and flexibility. In contrast, sample B2 (80% HDPE / 20% LDPE) recorded a lower hardness value (64.7) due to the dominance of HDPE crystallinity and the insufficient LDPE content to enhance homogeneity. Pure HDPE (B0) also showed a lower hardness (66.4), as its large crystalline domains tend to be brittle, reducing surface resistance. These findings are consistent with previous reports[25,26], which demonstrated that moderate LDPE content reduces crystallinity and improves the mechanical response of HDPE/LDPE blends.

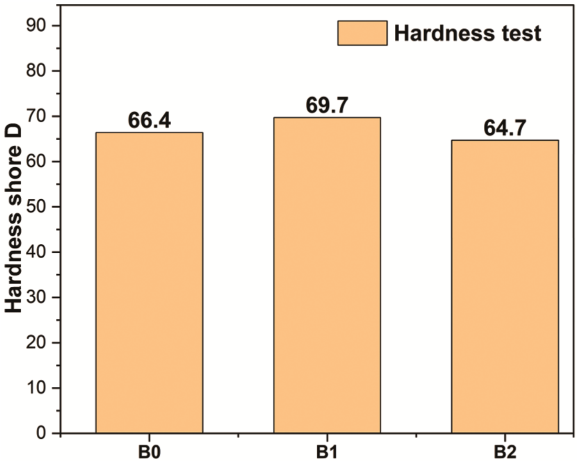

Fig. 3 — Shore D hardness values of the HDPE/LDPE blends (B0, B1, and B2)

3.3 Charpy Impact Test

Figure 4 shows that the Charpy effect results for samples (B0, B1, and B2) showed that the mixture composition strongly affects the hardness. Sample B1 (60% HDPE / 40% LDPE) recorded the highest impact strength (38.0 kJ/m²), compared to pure HDPE (B0 = 7.9 kJ/m²) and B2 (13.5 kJ/m²). The improvement in B1 is attributed to the higher LDPE content, which reduces crystallinity and enhances ductility, enabling greater energy absorption before fracture. In contrast, pure HDPE is highly crystalline and brittle, resulting in poor impact resistance, while the limited LDPE fraction in B2 was insufficient to counteract brittleness. These results are in good agreement with previous studies[27], which reported that increasing LDPE content in HDPE blends enhances toughness by improving chain mobility and reducing crack propagation.

3.4 Tensile Test

The tensile testof specimens (B0, B1, B2) showin Fig. 5 revealed clear differences in the mechanical response of the HDPE/LDPE blends. Pure HDPE (B0) exhibited the lowest tensile stress and elongation, reflecting its high crystallinity and brittle nature. In contrast, sample B1 (60% HDPE/40% LDPE) achieved the highest tensile strength and elongation, indicating that the addition of LDPE improved chain mobility and reduced excessive crystallinity, resulting in an optimal balance between stiffness and ductility. Sample B2 (80% HDPE/20% LDPE) exhibited intermediate behavior, with ductility higher than B0 but lower than B1, confirming that a moderate LDPE content yields the best compatibility and tensile performance. These observations are consistent with previous reports[28], which highlighted the beneficial effect of balanced HDPE/LDPE ratios on tensile behavior.

The tensile stress–strain behavior of the HDPE/LDPE blends is illustrated in Fig. 6, where the variation in tensile strength and elongation at break among B0, B1, B2 can be clearly observed.

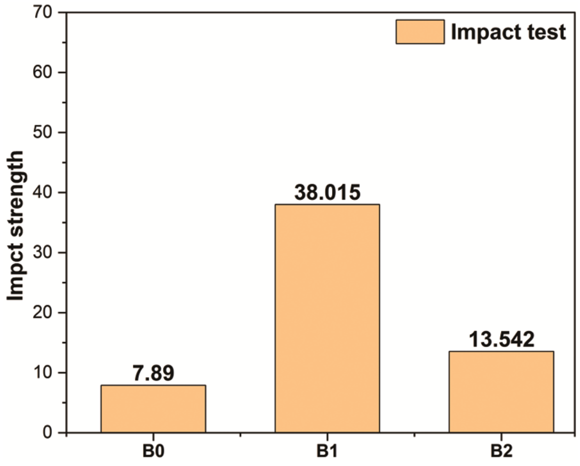

Fig. 4 — Charpy impact strength of the HDPE/LDPE blends (B0, B1, and B2)

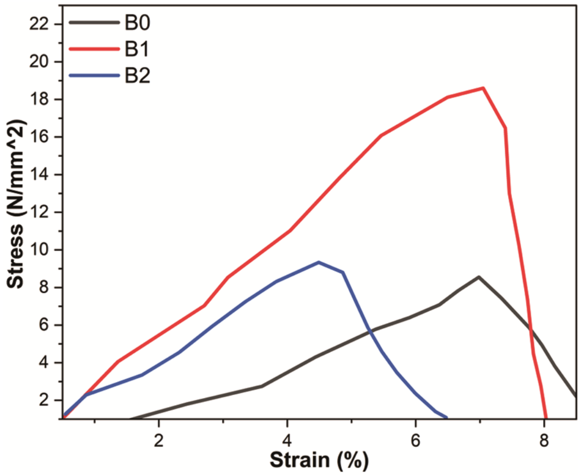

Fig. 6 — Tensile stress–strain curves of the HDPE/LDPE specimens (B0, B1, B2)

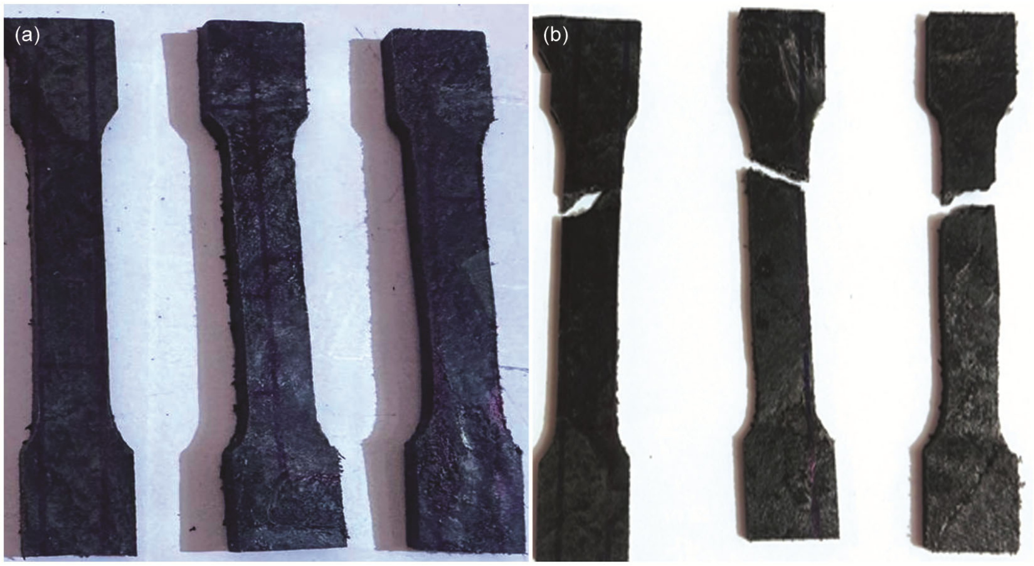

Fig. 5 — Tensile test specimens (a) before testing; and (b) after testing

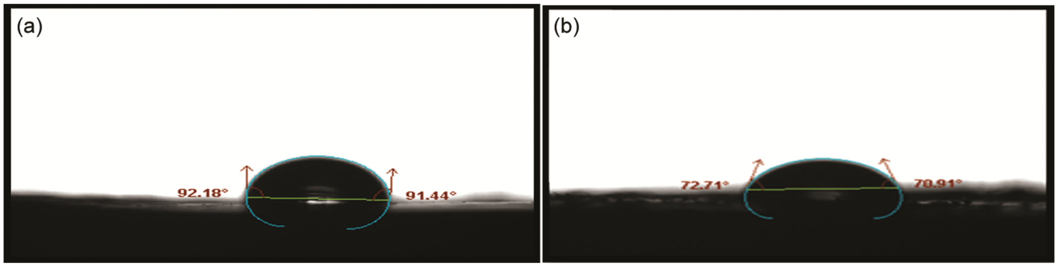

Fig. 7 — Contact angle measurements of HDPE/LDPE blends (a) B1; and (b) B2

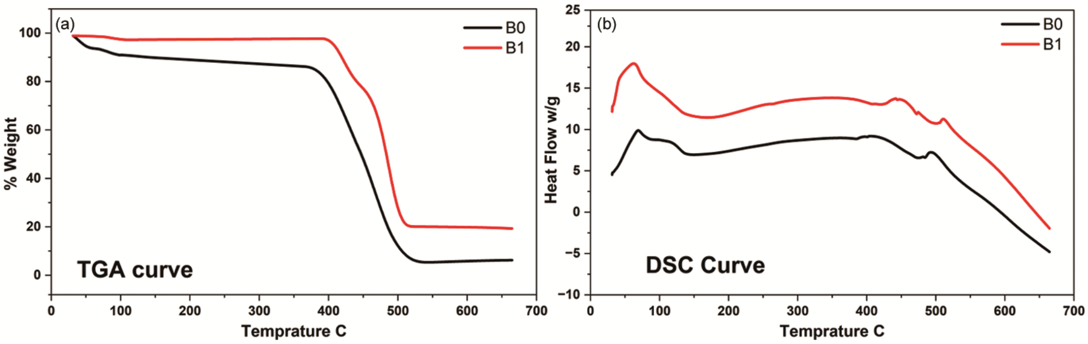

Fig. 8 — (a) TGA thermograms; and (b) DSC curves of the HDPE/LDPE blends

Table 1 — Comparative analysis of thermal properties of HDPE/LDPE blends

Sample	Beginning of decomposition (TGA) C°	End of decomposition (TGA)C°	Weight loss %	Melting point (DSC)	Heat of fusion ΔH(J/g)	degree of crystallinity (Xc)%
B1	392.99	482.37	92.67	62.87	872.4	29.8
B2	421.45	507.62	79.68	129	1185	40.4

3.5 Contact Angle Test

The contact angle measurements for sample (B1, B2) show in Fig. 7 highlighted clear differences in surface wettability between the blends. Sample B1 (60% HDPE / 40% LDPE) exhibited the highest contact angle (91°–92°), indicating enhanced hydrophobicity. This behavior can be attributed to surface segregation of non-polar chains and increased surface roughness, both of which lower the surface energy and limit droplet penetration. In contrast, sample B2 (80% HDPE / 20% LDPE) recorded a lower contact angle (≈71°), reflecting reduced hydrophobicity. The smoother surface and possible exposure of polar groups in B2 contribute to the lower water repellency. These results confirm that blend composition not only affects mechanical and thermal properties but also plays a key role in determining surface interactions, which are critical for packaging and coating applications.

3.6 Thermal properties (TGA & DSC)

The thermal analysis for sample (B1, B2) show in Fig. 8 confirmed that the HDPE/LDPE blends exhibit different stability profiles depending on composition. Sample B1 (60% HDPE / 40% LDPE) showed a clear crystalline melting peak around 62.9 °C, with thermal degradation starting at ~393 °C and peaking near 421 °C, indicating good stability. The presence of LDPE reduced the melting temperature compared to pure HDPE, while maintaining a stable degradation profile. Sample B2 (80% HDPE / 20% LDPE) demonstrated even higher thermal stability, with degradation extending up to ~507 °C and a broader melting transition (129–131 °C) as shown in Table 1, reflecting higher crystallinity but less uniform distribution. These results indicate that B1 provides a balanced combination of crystallinity and flexibility, while B2 is superior in withstanding elevated thermal conditions. Such behavior is consistent with earlier reports[29], which highlighted the role of HDPE dominance in enhancing decomposition resistance[30].

4 Conclusion

This study demonstrated that HDPE/LDPE blends exhibit tunable properties depending on composition. The 60/40 blend (B1) showed superior mechanical and surface performance, including hardness, impact strength, tensile behavior, and hydrophobicity. In contrast, the 80/20 blend (B2) provided enhanced thermal stability and morphological uniformity, making it more suitable for high-temperature applications. The blend ratio of 60% HDPE + 40% LDPE achieves the best results, combining flexibility and durability. These results confirm the versatility of HDPE/LDPE blends and highlight their potential for industrial applications such as packaging, insulation, engineering products and Plant irrigation pipes that require a balance between durability and stability.

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