

## Investigate the Influence of LDPE on the Mechanical and Thermal Characteristics of HDPE

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### Abstract

In this study, the effect of the addition of low-density polyethylene (LDPE) at different weight percentages (0, 10, 20, 30, 40, and 50) % The thermal and mechanical features of the high-density polyethylene (HDPE) were examined. The HDPE/LDPE combinations were prepared by using a twin-screw extruder. The mechanical properties (tensile properties, impact strength, hardness) , thermal properties using differential scanning calorimetry (DSC) were investigated , the Fourier Transform Infrared Spectroscopy (FTIR) test was also conducted to examine whether a chemical bond was formed in the combination or not And Surface morphological alterations of HDPE, LDPE, and HDPE/LDPE were analyzed using scanning electron microscopy (SEM). The results indicate a reduction in tensile strength and Young's modulus, accompanied by an increase in elongation at rupture. The impact strength was improved by the LDPE addition, while the Shore D hardness decreased. The DSC results indicate that the addition of LDPE reduced both the melting point and the degree of crystallinity. The FTIR indicated that there is a physical interaction between the two polymers. The SEM test revealed that the combination of two phases of LDPE exhibited superior softness compared to the LDPE sample, in addition to the presence of the phases.

**Keywords:** HDPE/LDPE combination; Tensile strength; Hardness; Impact resistance; DSC; FTIR; SEM.

### 1. Introduction

Polymer mixtures possess gained prominence in both investigation and implementation due to their critical role in addressing rising application demands. The amalgamation of chemically distinct polymers is a crucial technique in industrial manufacturing for customizing goods with enhanced material characteristics [1] . Polymer combination provide a method for integrating the advantageous characteristics of diverse polymers to improve various features unattainable with a singular polymer. Polymer combinations constitute a significant domain in the manufacturing of novel materials, exhibiting superior qualities relative to unadulterated polymers. They are important from both ecological compatibility and economic perspectives [2][3]. Five reasons exist for the implementation of polymer combinations: enhanced performance at a competitive cost, adaptability of performance in response to market evolution, extension of the efficacy of costly resins, repurposing of polymer waste, and the creation of a distinctive material regarding its processability and/or performance[4] . Currently, market pressures compel resin makers to deliver enhanced, cost-effective materials of exceptional

quality property combinations, not as substitutes for wood or steel, but to supplant existing polymers. Polymer mix technology can rapidly address emerging requirements. The characteristics of the combinations can be adjusted based on their intended application by the appropriate selection of constituent polymers [5].

A polymer mixture constitutes a type of material similar to metal alloys, consisting of a minimum of two polymers combined to form a new material with distinct features. Their total performance is contingent upon the characteristics and content of the morphology, the individual components of the mixtures, and their interactions qualities among the combination components. The insufficient interfacial adhesion among the polymeric ingredients leads to a reduction in mechanical parameters, such as strength of impact, strain at break, and Transition from ductile property to brittle property [6][7].

Numerous polymer mixtures have been investigated in recent years old. There exist five principal forms of polymer mixes: (thermoplastic-thermoplastic combination, thermoplastic-rubber combination, thermoplastic-thermosetting combination, rubber-thermosetting combination, and polymer-filler composites). Thermoplastic-thermoplastic combination, such as polyethylene (PE) combination, have garnered significant academic and commercial interest over the last decades due to their relevance in understanding the efficiency and processing characteristics of combination comprising various types of polyethylene (PEs). PE-PE combination comprise (low-density polyethylene)/(linear low-density polyethylene) (LDPE/LLDPE), high-density polyethylene/low-density polyethylene (HDPE/LDPE), (linear low-density polyethylene)/(high-density polyethylene) (LLDPE/HDPE), and (low-density polyethylene) / (linear low-density polyethylene)/ (high-density polyethylene) (LDPE/LLDPE/HDPE). combination has been shown to enhance the processability and mechanical qualities of pure polyethylene variants, including HDPE, LDPE, and LLDPE. The combination of polyethylene has become a prevalent industrial technique [8] [9].

Polyethylene (PE) can be categorized based on its density, which is influenced by its crystallinity level (degree of crystallinity) and the nature and quantity of branching. Three varieties of polyethylene are typically available: (HDPE), (LDPE), and (LLDPE) [10]. These polymers possess identical chemistry equations but vary in the population density of their molecular structures according to their formation processes. (HDPE) exhibits a straight structure with minimal or no branching and demonstrates a high degree of crystallinity. Conversely, (LDPE) possesses a disordered structure characterized by both long and short chain branches, exhibiting a lesser degree of crystallinity relative to (HDPE) [11]. Notwithstanding a fundamental discourse on the miscibility of HDPE with LLDPE or LDPE, it is recognised that the branching content of the branched component is the principal molecular factor affecting the miscibility of HDPE/LLDPE and HDPE/LDPE combinations [12]. The primary metric influencing the qualities of PEs is density, which serves as an indicator of short-chain branches. As crystallinity decreases with a fall in bulk density, the product becomes softer and more pliable, but clarity and toughness improve, and yield strength decreases [13].

Several studies on PE mixes have been published [12][14][8]. Polyethylene combinations may exhibit miscibility, partial miscibility, or immiscibility based on molecular characteristics involving the weight of molecular weight of molecular distribution, branching

distribution and content , and compositional dispersion [15]. It is noteworthy that the amalgamation of various PEs typically enhances comprehensive mechanical qualities and durability , provided that the appropriate selection and composition are attained. Consequently, it is intriguing to investigate the characteristics of various material combinations. This study examined the impact of (LDPE) content on the mechanical characteristics of (HDPE)/(LDPE) combination [16].

In this research, high-density polyethylene was combined with low-density polyethylene with different weight ratios and some mechanical tests(tensile, impact and hardness) were carried out for specimens, as well as a DSC examination for the purpose of studying the difference due to the addition of LDPE, and what is the best ratio possible to obtain for better mechanical and thermal properties.

## 2. Materials and Methods

High-density polyethylene (HDPE) and low-density polyethylene (LDPE) were procured from SABIC and utilised in this work as pellets. HDPE has a density of 0.94 g/cm<sup>3</sup> with a melt flow rate MFR of 15 g/10 min, and LDPE has a density of 0.92 g/cm<sup>3</sup> with a melt flow rate MFR of 25 g/10 g/10min. Both materials were used without purification or modification.

### 2.1. Specimen Preparation

The specimens were prepared by thermal extrusion (Extrusion), according to the following steps:

1. Mixing polymers: HDPE and LDPE were mixed in different proportions (0, 10, 20, 30, 40, 50) % LDPE, using a mechanical mixer at room temperature for 15 min.
2. Extrusion and forming: the HDPE and LDPE combinations were formed Utilising a twin-screw extruder at a screw speed of 50 rpm and a temperature range of 180-200 °C. the molten material then passes through two rotating rollers to form polymer sheets.
3. Thermal press: a thermal Press has been used to form uniform thickness sheets and then cut into standard specimens for tensile, impact and hardness tests.

## 3. Tests and analyzes (Characterization)

### 3.1. Testing of mechanical properties

#### 3.1.1. Tensile Tester

The Universal tensile Tester 5kN-wdw has been used to measure tensile characteristics including tensile strength, elongation at fracture, and elastic modulus. The test was performed according to ASTM-D 638IV[17].

#### 3.1.2. Impact Tester

A Charpy impact Tester gunt-50 equipped with a hammer of known initial power was used. The energy absorbed at fracture was recorded in units (kJ/m<sup>2</sup>). The test was performed according to ASTM-D 256[18].

### 3.1.3. Hardness Tester

The hardness was measured by the Shore D method to assess the effect of LDPE on surface hardness of HDPE. The test was performed according to ASTM-D2240[19].

### 3.2. Differential scanning calorimetry (DSC)

DSC analyses were conducted to ascertain the melting temps ( $T_m$ ) and the crystallinity levels of HDPE, LDPE, and HDPE/LDPE combinations. The experiments were performed using a SHIMADZU DSC-TA6WS differential scanning calorimeter under specified operating conditions: Heating from ambient temperature to 300 °C at a rate of 10 °C/min in a nitrogen atmosphere. [20]. The degree of crystallinity  $X_c$  was calculated according to the equation below:

$$X_c = (\Delta H_m * W_f / \Delta H_o) * 100\% \dots (1)$$

Where  $\Delta H$  is the enthalpy of material for melt taken from DSC and fully crystalline polyethylene which is 293 J/g,  $W_f$  weight fraction of HDPE [21], [22].

### 3.3. Fourier Transform Infrared Spectroscopy (FTIR) Test

Fourier transformation (FTIR) was performed using the FTIR-Affinity/Shimadzu. FTIR samples were tested after grinded and mixed with KBr in the proportion of 1:5 (Sample: KBr) and then pressed to form disks, then placing it in the specified unit. The test was performed in a wavelength 400-4000  $\text{cm}^{-1}$ .

### 3.4. Scanning electron microscopy (SEM) analysis

The changes in surface morphology of the samples (HDPE, LDPE, and HDPE/LDPE) films, were investigated using Field Emission Scanning Electron Microscope (TESCAN-VEGA3 55VP).

## 4. Results and discussion

### 4.1. Mechanical Properties Results

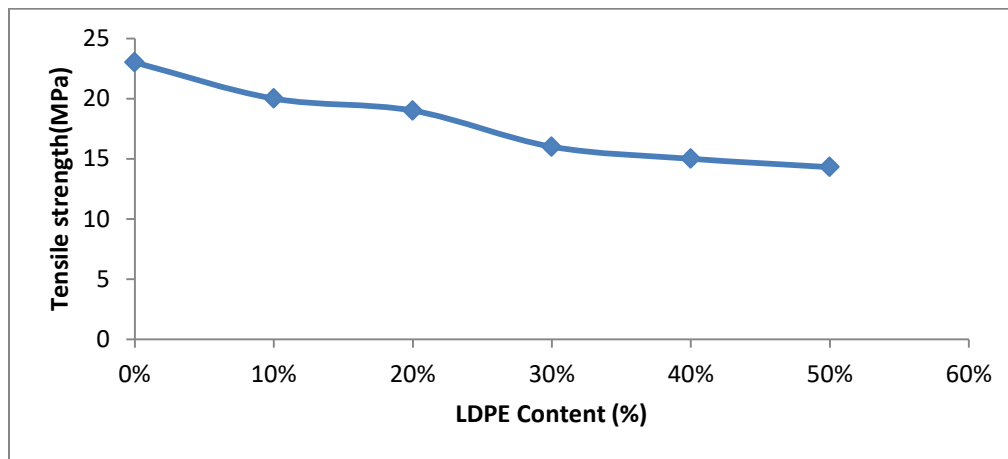
#### 4.1.1. Tensile Properties

From the results obtained from the tensile evaluation of HDPE specimens to which LDPE was added in different proportions, it was noted that the tensile strength has gradually decreased with increasing the percentage of addition, especially after the percentage of 20% LDPE, which indicates that random areas in the crystal structure of HDPE have increased due to the addition of LDPE[23]. And the lateral branching increased in the partial structure due to the LDPE, which led to the presence of gaps between the chains, therefore its stiffness has decreased and increased its elongation as in figures 1, 2 and 3 [24].

The results showed a significant decrease in tensile strength with an increase in the content of low-density polyethylene (LDPE), especially when exceeding the threshold of 20%. This behavior can be attributed to the fundamental structural Distinctions within the two kinds of polyethylene (HDPE) as well as low-density polyethylene (LDPE). High-density polyethylene (HDPE) is a semi-crystalline polymer with a very linear molecular structure, which facilitates dense Assembly and strong molecular interactions. These properties lead to high tensile strength and rigidity [5].

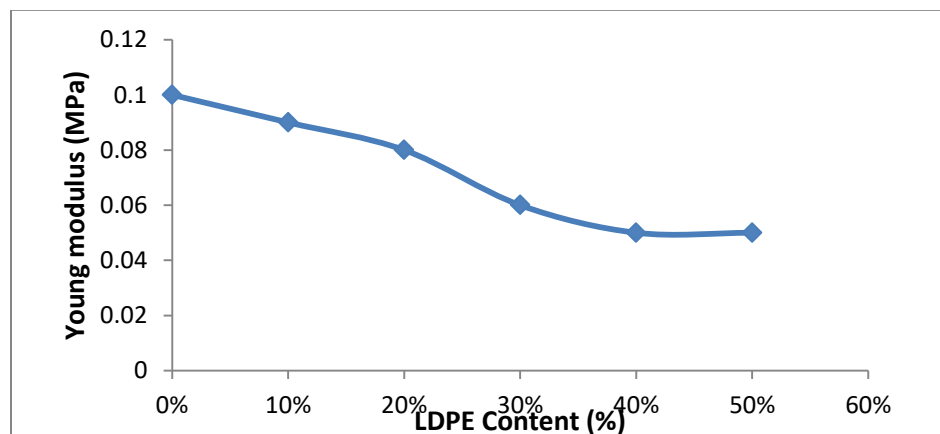
In turn, low-density polyethylene (LDPE) possesses a substantial quantity of long and short-chain branches along its primary structure, which disrupts the regular assembly of polymer chains and reduces crystallization. Hence, low-density polyethylene (LDPE) shows greater elasticity, but its tensile strength is lower compared to high-density polyethylene (HDPE). At low concentrations of low-density polyethylene (up to 20%), the mechanical behavior of the mixture is dominated by the high-density polyethylene phase, and the effect of low-density polyethylene on tensile strength is relatively minimal[25].

However, as the content of LDPE exceeds 20%, the presence of branched and less crystallized LDPE chains increases, which leads to a significant decrease in the overall crystal structure and cohesion of the mixture chains. This structural defect weakens the resistance of the material to tensile influences, which leads to a sharp decrease in tensile strength[26].



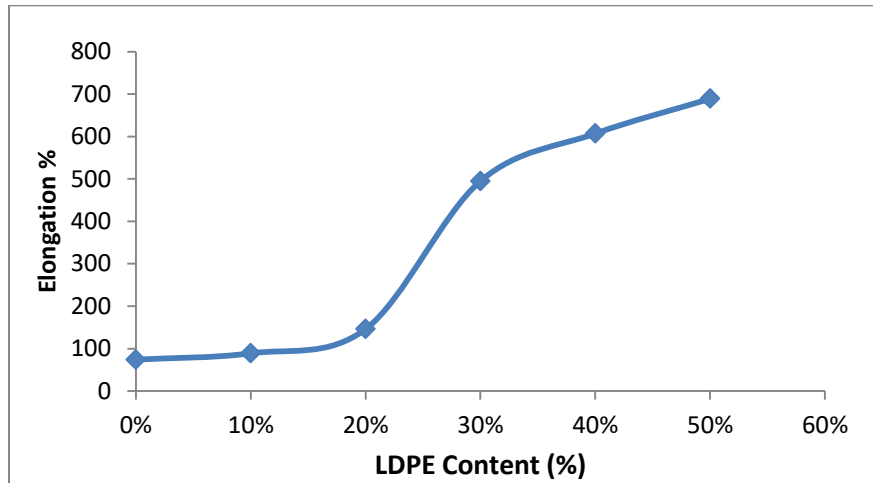
**Figure 1: Tensile strength of HDPE/LDPE combination vs LDPE Content.**

A decrease in the young modulus is also observed at the rate of increasing LDPE addition for the same reasons mentioned above, as the elasticity of the material increases and its stiffness decreases.



**Figure 2: Young modulus of HDPE/LDPE combination vs LDPE Content.**

On the other hand, the elongation will increase, and this is natural due to the increased elasticity of the material when adding and the frequent presence of side branches that form in the structure due to the addition of LDPE[27].

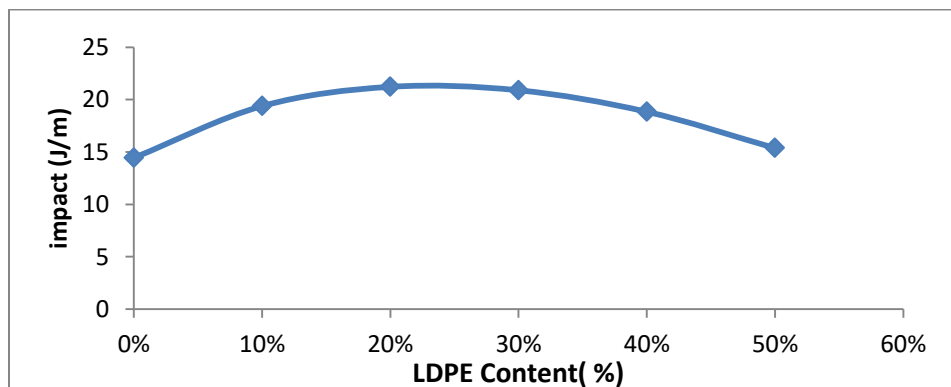


**Figure 3 Elongation of HDPE/LDPE combination vs LDPE Content.**

#### 4.1.2. Impact Test Results

The results showed that the impact resistance gradually improves when LDPE is added until it reaches the highest value at 20% LDPE, which shows The actuality of LDPE contributes to energy absorption and increase the elasticity of the mixture[28]. However, when this ratio is exceeded, the impact resistance begins to decrease due to the loss of the balance between hardness and elasticity, since a significantly increased LDPE content leads to a decrease in the bonding of polymer chains and an increase in ductility, which reduces fracture resistance.

This shows that the best ratio for improving impact resistance without negatively affecting other mechanical properties is about 20% of LDPE[28], these results coincide with the results of the tensile test obtained earlier , where it was noted that the tensile strength has decreased as well as the modulus of elasticity and the elasticity and ductility of the material has increased, especially in the addition ratio 20% of LDPE[28][28] owing to the impurities in the polymer structure that were mentioned earlier .



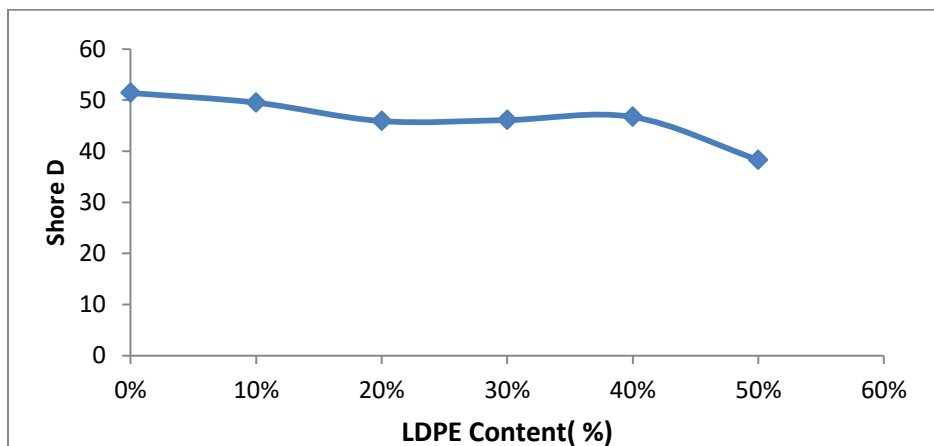
**Figure 4: Impact of HDPE/LDPE combination vs LDPE Content.**



#### 4.1.3. Hardness Test Results

The experimental findings indicated a gradual decrease in the hardness value (Shore D) of the HDPE material with increasing LDPE addition ratios. This behavior can be explained by referring to the structural and physical nature of both polymers. HDPE is characterized by a linear and relatively regular molecular structure and with a high degree of crystallization, which gives it high mechanical hardness as a result of the tight stacking of polymer chains[14].

In turn, LDPE has a structure with many lateral branching, which prevents molecular agglutination and reduces the degree of crystallization. When added to HDPE, such branching impedes Crystal organization and reduces structural density, which leads to a decrease in surface resistance to mechanical penetration, which is directly reflected in the hardness value measured by the Shore D scale [5] and that agreed with Previous mechanical results[5] .



**Figure 5: Shore D of HDPE/LDPE combination vs LDPE Content.**

#### 4.2. DSC results analysis

Figure 6 shows the thermal characteristics melting temperature  $T_m$  and melting enthalpy  $\Delta H_m$  of HDPE and HDPE/LDPE combination. It is found that both the melting temperature and the degree of crystallinity of HDPE were decreased by the addition of LDPE. This behavior is due to the increase of spaces between chains as LDPE added because LDPE has long chain branches that causes the reduction in  $T_m$  and thus reduce the crystallinity, this results are in agreement with the results of mechanical properties (tensile properties and hardness). Table 1 shows all the data extracted from DSC curves [29][30].

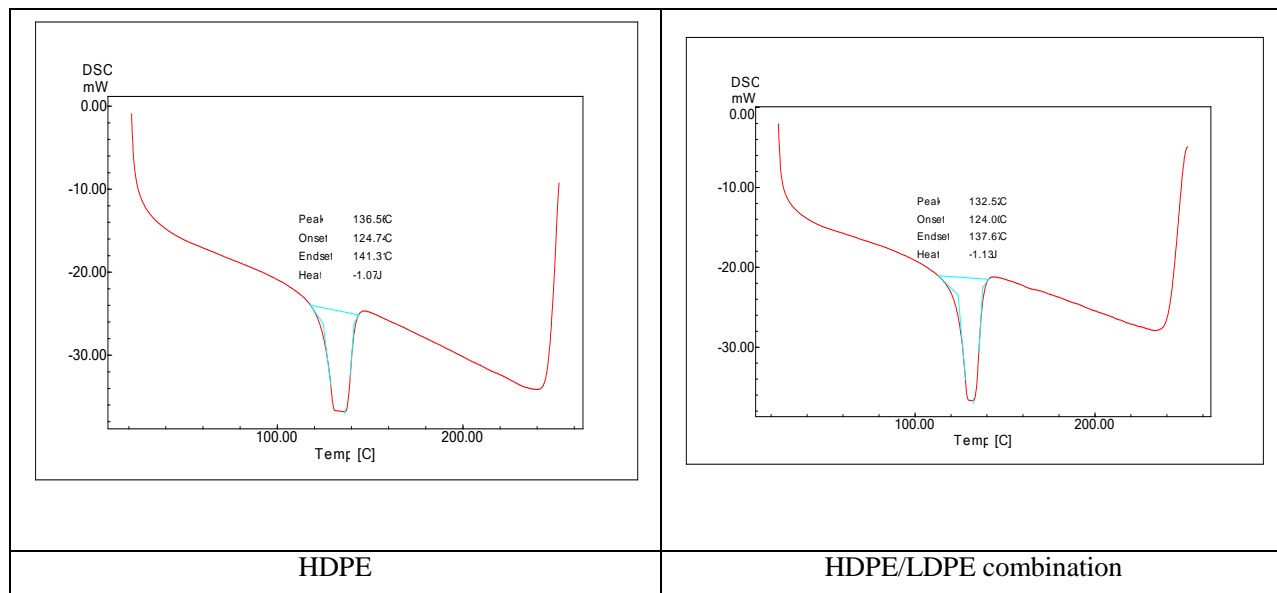


Figure 6: DSC curves of pure HDPE and HDPE/LDPE combination.

Table 1: DSC data of HDPE and HDPE/LDPE combination.

Samples	T <sub>m</sub> (°C)	ΔH <sub>m</sub> (°C)	X <sub>c</sub> (%)
HDPE	136.56	107	36.5
HDPE/LDPE	132.52	113	30.8

#### 4.3. FTIR results analysis

From the figure 7 below of FTIR for HDPE and HDPE/LDPE combination, it is found that the same bands for CH<sub>2</sub>, CH of symmetrical and asymmetrical stretching were observed for HDPE and HDPE/LDPE combination which means that there is only physical interaction between the two polymers and there is no chemical reaction. These results have good agreement with mechanical results [31].

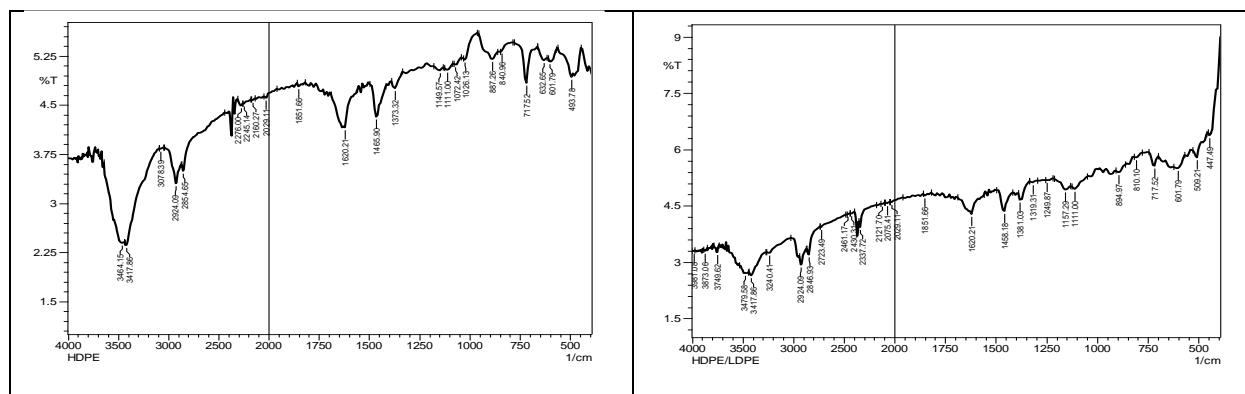


Figure 7: FTIR for HDPE and HDPE/LDPE samples.



#### 4.4. SEM image Results

Figure 8 show the SEM images for all samples (HDPE, LDPE, and HDPE/LDPE). From the figure it is obvious that HDPE sample shows a continuous smooth single phase with tiny defects while for LDPE the sample phase is corrugated and has no smoothness. For HDPE/LDPE sample the image show a mix from the two phases of HDPE and LDPE but the smoothness is much better when compared with LDPE sample, in addition the phases were appeared. This behavior could be attributed to long branches of LDPE which lower the ability to form uniform surface. These results are in agreement with [32].

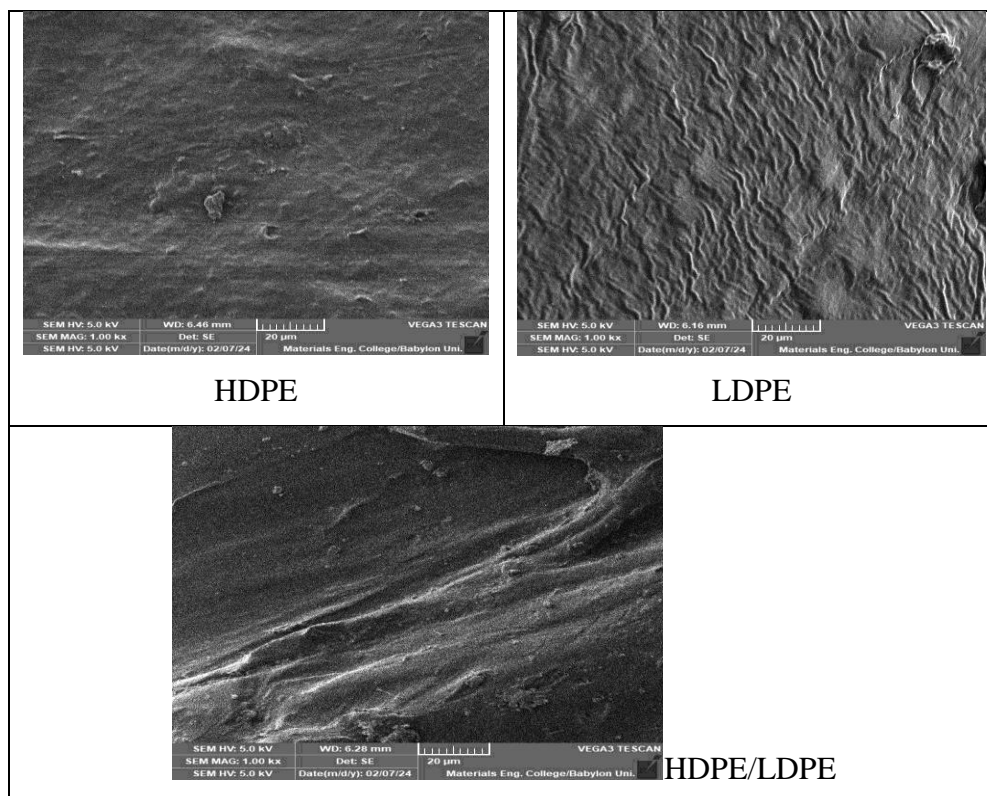


Figure 8: SEM images of all samples.

#### 5. Conclusion

In this research, it was found that mixing high-density polyethylene (HDPE) with different proportions of low-density polyethylene (LDPE) clearly affects the mechanical and thermal properties of the resulting material. Augmenting the LDPE content led to a reduction in tensile strength and Young's modulus, while elongation increased significantly, indicating increased ductility. Impact resistance also improved at specific ratios (20% and 30%) before declining at higher ratios, indicating an optimal LDPE addition ratio to achieve a balance between toughness and ductility. Hardness gradually decreased with increasing LDPE, reflecting its effect on the rigid structure of HDPE. DSC results also showed a decrease in melting point and crystallinity, confirming that mixing the two materials affects the arrangement of the polymer chains. Therefore, it can be concluded that using LDPE as a modifier for HDPE can be beneficial for improving certain properties such as ductility and impact resistance, provided the

addition ratio is controlled to suit the required applications. FTIR show that there is no new band appear or disappear by the addition of LDPE to HDPE which means that there is only physical interaction. SEM images show that two phases were appeared by LDPE addition.

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## التحقيق في تأثير البولي إيثيلين المنخفض الكثافة على الخصائص الميكانيكية والحرارية من البولي إيثيلين عالي الكثافة

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### الخلاصة

يهدف هذا البحث إلى دراسة تأثير إضافة البولي إيثيلين منخفض الكثافة إلى البولي إيثيلين عالي الكثافة بنسب وزنية مختلفة (0 ، 10 ، 20 ، 30 ، 40 و 50) % على الخواص الميكانيكية والحرارية للمزيج الناتج. تم تحضير الخلطات باستخدام آلة بثق ثنائية اللولب للحصول على مزيج متجانس من البولي إيثيلين عالي الكثافة /البولي إيثيلين منخفض الكثافة. تضمنت الاختبارات الميكانيكية خصائص الشد والصدمة واختبارات الصلادة لجميع العينات. وبالإضافة إلى ذلك، أُجري اختبار المسح التفاضلي للسعرات الحرارية (DSC) للبولي إيثيلين عالي الكثافة النقي ومزيج يحتوي على 20 في المائة من البولي إيثيلين المنخفض الكثافة. كما تم إجراء اختبار التحليل الطيفي بالأشعة تحت الحمراء لتحويل فورييه (FTIR) لفحص ما إذا كان قد تم تشكيل رابطة كيميائية في الجمع أم لا ، وتم تحليل التغيرات المورفولوجية السطحية من LDPE ، HDPE ، و LDPE/HDPE باستخدام المسح المجهر الإلكتروني (SEM) أشارت النتائج إلى أن إضافة البولي إيثيلين المنخفض الكثافة أدى إلى انخفاض تدريجي في مقاومة الشد ومعامل المرونة، بينما لوحظت زيادة كبيرة في الاستطالة، خاصة بعد تجاوز 20 % من البولي إيثيلين المنخفض الكثافة. أظهرت نتائج اختبار التأثير أيضا تحسنا في مقاومة الصدمة عند 20% و 30 %، يليه انخفاض عند التركيزات الأعلى. الصلادة انخفضت تدريجيا مع زيادة محتوى البولي إيثيلين المنخفض الكثافة. وأشار تحليل (DSC) إلى أن العينة التي تحتوي على 20 % من البولي إيثيلين المنخفض الكثافة لديها نقطة انصهار أقل وبلورية أقل ، مما يعني أن البنية الداخلية للمادة تغيرت بسبب الخلط. وأشار FTIR أن هناك تفاعل فيزيائي فقط بين البوليمرات . كشف اختبار SEM أن الخليط لكل من البولي إيثيلين عالي الكثافة و البولي إيثيلين المنخفض الكثافة أظهر نعومة فائقة مقارنة بعينة البولي إيثيلين المنخفض الكثافة ،. هذه النتائج تثبت أن تعديل HDPE مع إضافة LDPE يمكن أن تحسن خصائص مثل المتانة ومقاومة الصدمة مع الأخذ بعين الاعتبار الآثار السلبية على الجساءة والصلادة.

الكلمات الدالة:- مزيج (LDPE/ HDPE) ؛ مقاومة الشد؛ مقاومة الصدمة؛ الصلادة؛ DSC؛ FTIR؛ SEM .