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**Sameer A. Awad**

*University of Anbar, Department of Chemistry, Ministry of Higher Education and Scientific Research, Ramadi 31001, Iraq*
*Corresponding author. E-mail: Sameer.msc1981@gmail.com*

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# INVESTIGATION OF THERMAL AND MECHANICAL CHARACTERIZATIONS OF HIGH-DENSITY POLYETHYLENE/DATE PALM COMPOSITES

**The article aims to study the impact of date palm powder (DPP) on the mechanical and thermal characterizations of a high--density polyethylene (HDPE) matrix. HDPE composites enhanced with ratios varying from 5 to 20 wt.% DPP were produced by means of a twin-screw extruder. The results indicate that incorporating between 5 to 20 wt.% DPP in pure HDPE led to an increase in the tensile strength and Young's modulus, while the elongation at break decreased. Furthermore, the results of thermal gravimetric analysis (TGA) revealed that incorporating DPP into pure HDPE improved the thermal stability owing to a reduction in the interfaces between DPP and the pure HDPE matrix, resulted in brittle behavior, and enhanced the great crosslinking of pure HDPE.**

**Keywords: high-density polyethylene, date palm, tensile strength, thermal properties**

## INTRODUCTION

Composite materials can be formed of two or more material components, and they do not dissolve or blend into each other. In composites, natural fillers comprise the dispersed phase in polymeric materials. Natural fillers of ferstiffness and strength in addition to better chemical and mechanical properties for composites [1-4]. Interest in natural fibers has grown worldwide due to their low-density, good thermal and mechanical properties, hardness, low cost, and eco-friendliness [5]. Furthermore, natural fibers are considered biodegradable materials, are often considered only for markets that require low costs and high production rates and can accept low performance, and some natural fiber composites can be produced on a large scale without the displacement of other crops [6].

It is essential to achieve strong adhesion between the fibers and the polymer matrix to gain the advantages of composites obtained from natural fibers. Fibers are naturally hydrophilic, whereas the matrix is hydrophobic, forming higher polymer matrix adhesion [5, 7, 8]. HDPE is considered one of the best commonly utilized plastic materials [9-12]. HDPE is characterized by low shrinkage, easy molding, and high strength [13]. On the other hand, *natural* fillers are gaining attention from researchers to produce polymer *composites* owing to their ecofriendly nature and sustainability [14,15]. Liu et al. [16] examined the mechanical characterizations of banana fiber-reinforced HDPE/PA-6 composites. They noticed that the modulus and flexural strength were enhanced by increasing the banana fiber loading to 48.2 wt.%, but the impact toughness was reduced significantly. In this study, date palm powder (DPP) was selected to reinforce a high-density polyethylene (HDPE) matrix to improve the thermal and mechanical properties.

## MATERIALS AND METHODS

### Materials

The date palm seeds were collected locally. HDPE with a density of 0.955 g/mL was used as the matrix, supplied by the Indian Chemical and Petrochemical Manufacturing Company.

### Preparation of DPP

The date palm seeds were washed and put in an oven at 50°C for 48 h to eliminate moisture. Next, the seeds were dried and ground, utilizing a grinder (Breville Grain mill, USA) at 350 r/min$^{-1}$. After grinding, they were placed in a sieve with a mesh size of 600 μm.

### HDPE composite fabrication

First, the needed quantities of HDPE and DPP were fully blended utilizing a mixer (Thermo Scientific HAAKE Rheomix QC lab mixers (UK) internal mixer) to achieve a homogenous mixture. Then the mixed solution was transferred to a twin-screw extruder (KBL65-26 Foshan Kebeln Plastic Machinery Co., Ltd. China) at the temperature of 180°C and a screw velocity of 10 r/min$^{-1}$. Next, the extruded samples were removed

from the extruder and compacted in a Carver press at 140°C for 30 min to obtain a thin film (20 x 20 cm) having a 2 mm thickness. The HDPE matrix was reinforced with the DPP powder at different loadings (0, 5, 15, and 20 wt.%).

### Thermal Gravimetric Analysis (TGA)

All the samples were tested utilizing a TGA analyzer (TGA Q500, TA Instruments) under nitrogen, and the temperature range was from 50 to 600°C. The weight of the specimens (HDPE and HDPE/DPP) was 5-10 mg and the heating rate was 10°C/min$^{-1}$. The thermal decomposition temperature of the composites was confirmed within the range of the abovementioned temperatures.

### Tensile tests

Specimens of the composites were tested utilizing an Instron tensile machine (Testometric, M500-50AT), UK, based on the ASTM D 638 standard. The cross head speed was about 20 mm/min. Three specimens were tested for each composite.

### Water absorption test

The water absorption specimens were immersed completely in distilled water for different lengths of time. The specimens were dried using tissue paper to eliminate any residual water from the surface prior to weighing, utilizing a sensitive scale. Three specimens for each structure were dried at 80°C for 24 h using an oven. The water absorption test was performed according to ASTM D 570-98. The water absorption (WA) of the specimens was calculated using Equation (1)

$$W_A\,(\%) = \frac{W_t - W_0}{W_0}\,x100 \qquad (1)$$

where $W_0$ is the initial specimen weight, and $W_t$ represents the immersed specimen weight.

## RESULTS AND DISCUSSION

### Thermal degradation analysis of HDPE/DPP composites

The thermal decomposition performance of the pure HDPE and HDPE/DPP composites is displayed in Figures 1 and 2. $T_{onset}$ denotes the initial decomposition temperature and is a significant element indicating thermal stability. The maximum decomposition temperature ($T_{max}$), $T_{onset}$ and the residual yield % at 500°C are summarized in Table 1. The maximum degradation temperatures for HDPE and the HDPE/DPP (5, 15, and 20 wt.%) composites were found to be 405.5, 407.2, 415.5, and 434.7°C, respectively, while $T_{onset}$ of HDPE was 372.5°C in comparison to 5, 15, and 20 wt.% DPP in HDPE which was 374.4, 379.5, and 388.7°C, respectively. According to Figure 1 and Table 1, DPP caused a significant decrease in the thermal endurance of the HDPE matrix. The thermal decomposition residual yield of the composites was slightly improved by increasing the DPP loading. The residual yield of HDPE was 1.2%, while for the HDPE with different DPP loadings (5, 15 and 20 wt.%) the residual yields were 1.5, 3.7, and 8.7%, respectively. The values of the thermal properties are presented in Table 1 and show that the thermal stability of HDPE matrix rose with increasing the DPP loading.

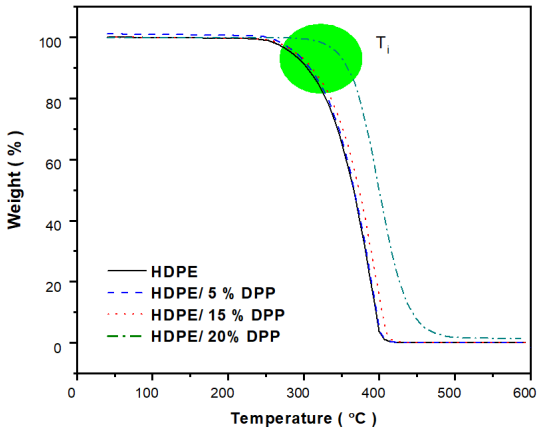


Fig. 1. TGA curves for HDPE and HDPE/DPP composites

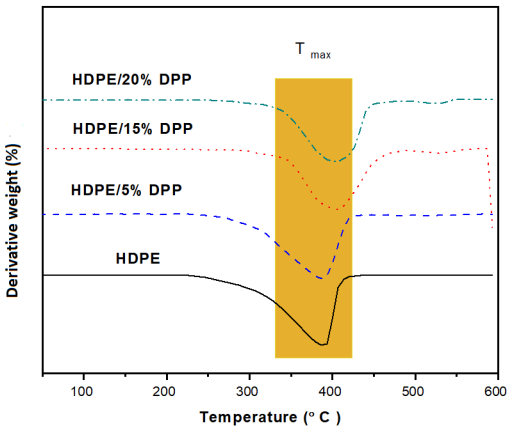


Fig. 2. DTG curves for HDPE and HDPE/DPP composites

**Table 1. Results of TGA thermograms of pure HDPE and HDPE/DPP composites**

| Material | $T_{onset}$±0.5 [°C] | $T_{max}$±0.5 [°C] | Residual yield [%] |
|---|---|---|---|
| Pure HDPE | 372.5 | 405.5 | 1.2 |
| HDPE/5%DPP | 374.4 | 407.2 | 1.5 |
| HDPE/15%DPP | 379.5 | 415.5 | 3.7 |
| HDPE/20%DPP | 388.7 | 434.7 | 8.7 |

### Mechanical properties

The mechanical characteristics of the composites are shown in Figure 3. The DPP/HDPE composites exhibited higher tensile strength and Young's modulus compared to the HDPE matrix.

 

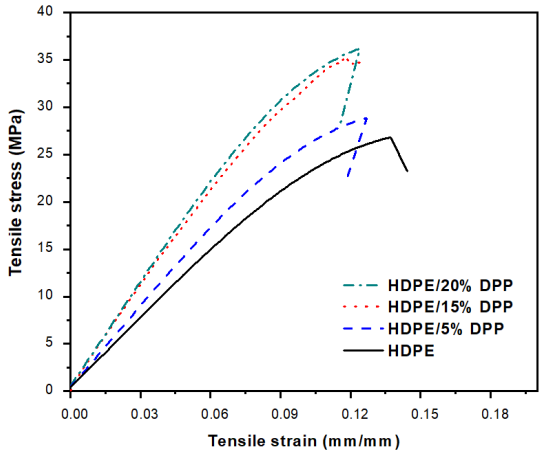


Fig. 3. Tensile stress-strain curves of HDPE and HDPE/DPP composites

It is obvious from Figure 4 that the tensile strength improved with increasing the loading of DPP from 5 to 20 wt.% in comparison to pure HDPE. Figure 3 shows that the significant loading of 20% DPP increased the tensile strength to 36±4.5 MPa compared with pure HDPE, which was 26±2.5 MPa. The results of the Young's modulus revealed a significant increase at the 20 wt.% DPP loading, 417±25, in comparison to the lower loadings (5 and 15% DPP) and pure HDPE, which was 403±22 MPa and 326±16 MPa, and 280±15 MPa, respectively, as presented in Figure 5.

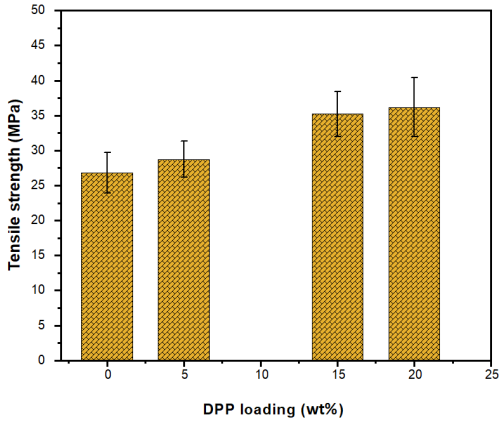


Fig. 4. Tensile strength of HDPE and HDPE/DPP composites

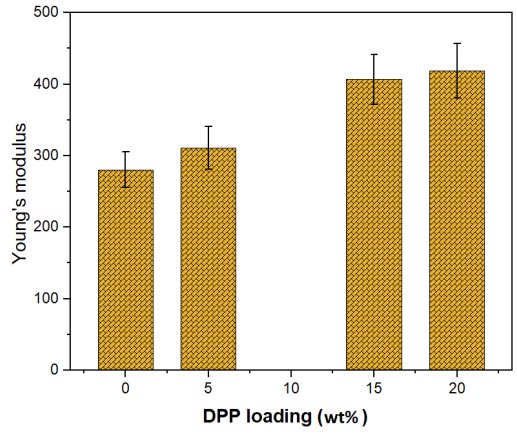


Fig. 5. Young's modulus of HDPE and HDPE-DPP composites

The addition of different loadings of DPP did not cause significant changes in the elongation at break. Instead, the strain at break grew with increasing the DPP loading in the HDPE matrix. The elongation at a break of the composite with 20 wt.% DPP in the HDPE matrix decreased to 12.8±1.2% against 14±1.4% for the pure HDPE, as shown in Figure 6. This may be owing to the high DPP content in the HDPE matrix, which improved the interfacial interaction with increasing the reinforcement content [17, 18].

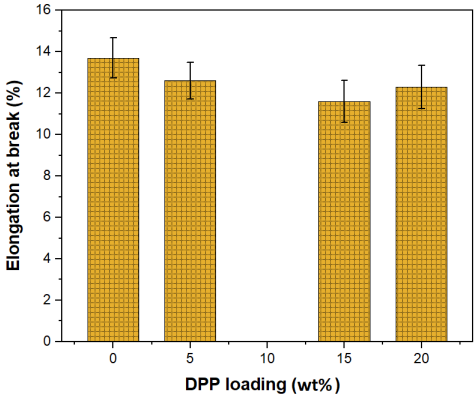


Fig. 6. Strain at break of HDPE and HDPE-DPP composites

## Water absorption of HDPE composites

The water absorption characterizations of the pure HDPE and HDPE/DPP composites are illustrated in Figure 7. The results showed that the percentage of water absorption for the HDPE/DPP composites decreased with increasing the weight of DPP reinforcement and time, the lowest water absorption being 1.3% for the 20% DPP loading reinforcement at the time of 700 hours, while the 5 and 15% DPP in the HDPE matrix exhibited a slight increase (1.42 and 1.36%, respectively) in comparison to the 20% DPP loading. On the other hand, the pure HDPE matrix exhibited the highest water absorption percentage, 1.45%. The decrease may be attributed to the increased surface area of the reinforcement in the DPP matrix, leading to a reduced number pores [19].

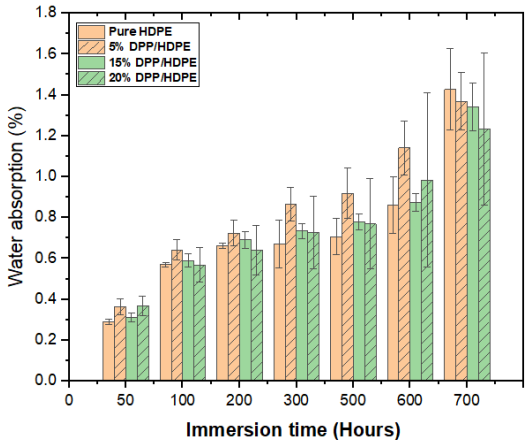


Fig. 7. Water absorption values versus immersion time of pure HDPE and HDPE/DPP composites

## CONCLUSIONS

This study demonstrated that DPP could be utilized as an effective reinforcement material for an HDPE matrix. DPP added to HDPE in amounts from 5 to 20 wt.% increased the maximum decomposition temperature of HDPE. The incorporation of DPP into the HDPE matrix resulted insignificant improvements in the tensile and flexural strength. Furthermore, HDPE/5% DPP, HDPE/15% DPP, and HDPE/20% DPP exhibited higher tensile strength and Young's modulus values than neat HDPE.

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