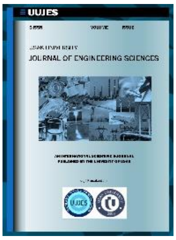

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Research article

MODIFIED PERFORMANCE OF MECHANICAL, THERMAL, AND PHYSICAL PROPERTIES OF HIGH-DENSITY POLYETHYLENE – CORN FLOUR COMPOSITES

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Abstract

A twin-screw extruder synthesized the high-density polyethylene (HDPE)/corn flour (CF) composites. The properties of different contents of CF (10, 20, 25wt. %) has been evaluated and analyzed in detail, including the mechanical, thermal, and physical properties. Results exhibited the high interfacial adhesion between HDPE and CF. The tensile strength of HDPE composites with higher loading 25%CF showed tensile strength which was 37% higher than the neat HDPE. Similarly, modulus of elasticity and flexural strength parameters increased by the ratios 0.5% and 14% respectively, however, impact strength decreased by the ratio 48%. Results also showed that thermal conductivity is improved and it reduced by 42% with a higher amount of CF (25%Wt). Water absorbance increased with increasing CF in HDPE matrix.

Keywords: *High-density polyethylene; corn flour; composites; tensile strength, thermal stability; impact strength.*

1. Introduction

Composite materials contain two or more materials, one of them is an additive and another one is a matrix material [1-3]. Thermoplastic composites consist of mixtures of thermoplastics such as polyethylene, polypropylene and a natural filler such as corn flour, natural fillers, and fillers. They are important fillers for several uses and due to their low cost, lightweight and environmental benefits, low density and etc. they are used as relatives to inorganic-filled systems [4, 5]. With the increasing concern for the effect of human activities on nature, the need of natural fillers as fillers in the plastic manufacturing

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has increased more. The idea of using natural fillers instead of synthetic fillers was developed to support composites, particularly polymer composites [6-8].

Natural fillers from renewable natural resources provide the possibility of performance as a biodegradable reinforcing material instead of the use of inorganic fillers such as carbon fillers and glass. The natural fillers supply various benefits including low cost, low density, high strength and modulus, renewable nature, the lack of combined health hazards, broad accessibility [9-12]. Thermoplastics are combined with natural fillers to create composites. They provide many of interests such as low densities and low-cost nonabrasive nature [13]. The high filling with natural fillers offers significant features such as low energy consumption, and biodegradability [14,15]. The utilization of plastic and natural fillers (corn flour, wood flour, etc.) for the industrial composites may service the environment by decreasing the landfilling and may improve the recycling [16,17].

High-density polyethylene is one of the best polymers that are used as plastic composites. The nature of highly crystalline HDPE provides important thermal stability, excellent mechanical properties, and more chemical resistance [18]. HDPE was utilized as matrix material for natural composites, with an area of essential properties [19-21]. Many research works showed that the addition of natural fillers (corn flour, wood flour etc.) into HDPE matrix exhibited a useful approach, which helped to improve the properties of polymers [22]. Adding natural filler into the matrix plastics produce reduced elasticity and poor impact resistance [23]. Also, the addition of natural fillers to thermoplastic polymers is followed by an essential increase in the melt viscosity [24]. From previous studies, it becomes evident that the addition of natural fillers has more significant improvement effects on thermal and mechanical properties. The main aim of this study is to examine whether CF contents could enhance and improve the thermal and mechanical properties.

2. Materials and method

2.1. Materials

High-density polyethylene (HDPE) was used as a matrix material and provided by Indian Chemical and Petrochemical Manufacture (CPMA). Corn flour was collected from corn maize seeds from the west of Iraq (Ramadi City), dried in 50 for 5 h and then granulated into 150μm-mesh size flours using micron mesh sieve.

2.2. Preparation of HDPE/CF composites

Granulated HDPE and corn flour (CF) were blended in a high-intensity mixer for 5 minutes to produce a homogeneous mixture that showed better dispersion between the HDPE and CF fillers (CF fillers disappear completely between the HDPE particles at the mixing). The homogenous mixture was mixed in a laboratory scale single-screw extruder with a screw speed of 40 rpm, and the temperature of the extruder was confirmed at 300°C. The mixture was collected, cooled and granulated into pellets. Finally, pellets were compressed in the hot press on molds for 5 minutes at 200 °C and then cooled for 20 minutes.

2.3. Characterisations

2.3.1. Mechanical tests

According to the standard ISO 527-1, tensile tests were conducted by using an Universal machine, Instron 1130 tester, under the load of 1000 N and at the test speed 2 mm.min^{-1} Flexural analyses of samples were carried out according to the standard ASTM D790-03, using Instron 1130 tester. Notched Izod impact strengths were tested by using Izod /

Charpy Impact Tester - QPI-IC according to the ASTM D 256-05. Four samples were tested for each group.

2.3.2. Thermogravimetric analysis (TGA)

Thermogravimetric (TGA) tests were performed, utilizing a Perkin Elmer instrument (Switzerland) MT5 thermogravimetric analyzer. The weight range of samples is between 5 and 10 mg, and a heating rate is 10 °C min^{-1}. HDPE and HDPE composites were heated from room temperature up to 500 °C to evaluate the thermal degradation of HDPE and HDPE/CF composites. All tests were applied under a nitrogen atmosphere.

2.3.3. Thermal conductivity

Thermal conductivity refers to the heat rate that transfers within a body of material for an assumed temperature change. The rate of heat showed over the sample is:

$$Q = \frac{KA(T1 - T2)}{L} \tag{1}$$

where L is the sample thickness, A denotes the cross-section area of the samples under tests. Besides, K symbolises thermal conductivity, Q equals to the rate of heat transfer and ($T1$-$T2$) is the temperature difference.

$$Q = mc(\partial T/\partial t)T2 \tag{2}$$

$$K = \frac{mc(\partial T/\partial t)T2}{A(T1 - T2)/L} \tag{3}$$

The samples were tested, using Heat Flow Meter 446 Instrument (NETZCH).

2.3.4. Water absorption

Samples were immersed entirely in distilled water and reported at various immersion times. The samples were dried by tissue paper to remove residual water from the surface of samples before weighing by using a sensitive balance. Four samples for each composition were dried in an oven for 24 h at 80°C. The tests of water absorption were carried out according to the ASTM D 570-98 method. The water absorption (W_A) of samples was calculated utilizing the following equation:

$$W_A(\%) = \frac{W_t - W_0}{W_0} \times 100 \tag{4}$$

where W_0 is the weight of the original specimen and W_t is the weight of the immersed samples in time t.

3. Results and discussion

3.1. Mechanical properties

Table 1 shows the results of the mechanical properties of HDPE/CF composites. From this table, it is noticed that tensile strength increases with an increase in the percentages of CF content. Higher tensile strength (42MPa) is seen in the higher content (25 wt.% CF) because the force of tensile is shifted from polymer to filler effectively. The tensile properties of HDPE/CF composites with different CF contents are shown in Table 1. The tensile strength of HDPE/CF (10, 20, and 25 wt. %) loading level increased by 8.1 %, 24.5%, and 37.7%, respectively, and modulus of elasticity improved by 1~7.5%. Strain at break decreased with the increase of 10, 20, 25 wt. % CF contents in HDPE (7.5%, 6.2%, and 3.5%), compared to strain at break of HDPE (8.4%). Improvements in tensile strength and modulus of elasticity were due to a homogeneous distribution of CF particles in HDPE.

Flexural properties (flexural strength and modulus) of HDPE/CF are exhibited in Table1. Compared to HDPE, flexural strengths increased by 4%, 5.7%, and 14.2, for CF 10, 20, and 25 wt. % loading levels respectively. Flexural modulus improved by with a higher content of CF (25 wt. %) 1255MPa, compared to HDPE (980.5MPa). It can be seen that 25 wt. %CF suggested a positive effect on tensile modulus, which might be due to increased strength and stiffness.

Flexural modulus increased by 0.5%, 8.6%, and 28% for 10, 20, 25 wt. % CF contents in HDPE (Table 1). These results state that the low CF loading of 10 wt. % has a minimal effect on the mechanical properties of HDPE/CF that is attributed to the fact that the tensile properties are dominated by the CF filler reinforcement rather than the HDPE. The impact test is designed to measure the ability and stated by the energy or the intensity which is the power per surface area. The fundamental condition of the impact test is to fracture the specimen under enough load. The effect of CF contents to the property of the Izod impact strength is shown in Table 1. The impact strength exhibited a regular decrease by increasing CF content in the HDPE. The impact strength of HDPE with 25%CF was 48% smaller than that of neat HDPE. The impact strength tests showed that the higher contents of CF improved the interface adhesion between CF filler and HDPE polymer.

Table 1 Mechanical properties of HDPE and HDPE/CF composites.

Specimen ID	Tensile Strength (MPa)[1]	Modulus of Elasticity (MPa)	Strain at Break (%)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Impact Strength (J/m)
HDPE	30.5 ± 2.5	255.5 ± 25	8.4 ± 0.5	17.5 ± 2.3	980.5 ± 55	38.5 ± 0.5
HDPE/10%CF	33 ± 1.7	258.4 ± 20	7.5 ± 0.7	18.2 ± 2.4	986 ± 60	37.6 ± 1.2
HDPE/20%CF	38 ± 3.2	263.5 ± 45	6.2 ± 0.3	18.5 ± 1.7	1065 ± 75	28 ± 1.5
HDPE/25%CF	42 ± 1.5	274.7 ± 60	3.5 ± 0.9	20 ± 2.5	1255 ± 70	20 ± 0.7

3.2. Thermal degradation of HDPE and HDPE/CF composites

TGA thermograms supported the thermal degradation of composites materials under a nitrogen atmosphere, and the heating rate for each sample was about 10°C/min. Fig. 1 shows the TGA thermograms and Fig. 2 shows derivatives (DTG) that were obtained from the rate of Tg curves (the maximum temperature, Tmax) of HDPE compared to those of HDPE/CF composites. The onset temperature (T_{onset}) exhibited more information based on TGA curves (Fig. 1).

The summary of the thermal stability for each sample explaining the onset temperature (T_{onset}), the temperature at weight loss ($T_{10\%}$ and $T_{50\%}$), maximum temperature (T_{max}), and residue for each sample are exhibited in Table 2. From results in Table 2, HDPE filled with 25 wt. %CF showed thermal stability higher than that of HDPE matrix. The 25wt.% CF showed initial decomposition temperature (T_{onset} = 345°C) that was higher than those of other CF contents. T_{onset} values of 10 wt.% CF, 20 wt.% CF, and neat HDPE are 319°C, 338°C, and 290°C respectively. Temperatures, (T_{10}) and (T_{50}) are due to 10% loss and 50% loss. According to the results in Table 2, the thermal decomposition at (T_{10}) of 25 wt. % CF in HDPE sample has higher decomposition (T_{10} °C= 358°C) than those of others, (325° C, 350°C, and 311°C). At T_{50}, the decomposition temperature of 25wt.%CF (401°C) is higher than 10% (379 °C), 20% wt.CF (388°C), and neat HDPE (368°C). The maximum temperature (T_{max}) showing the value of thermal stability is higher for the HDPE with 25%

CF (414 °C) as shown in Table 2. The HDPE composite samples exhibited resistance to weight loss (residue at 500°C) as 1.2%, 3.5%, and 5.7 % for 10% CF, 20% CF, and 25% CF content respectively (0.5% for HDPE). These results indicated that presence of higher CF content provided more resistant to loss of mass at T_{onset}, T_{10}, T_{50}, and T_{max}, because the high interaction and increased crosslinking density between CF and HDPE bonds.

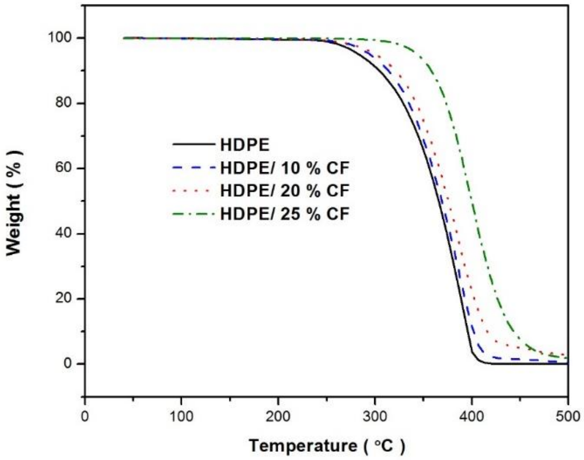

Fig. 1 Thermogravimetric curves for HDPE and HDPE/CF composites**.**

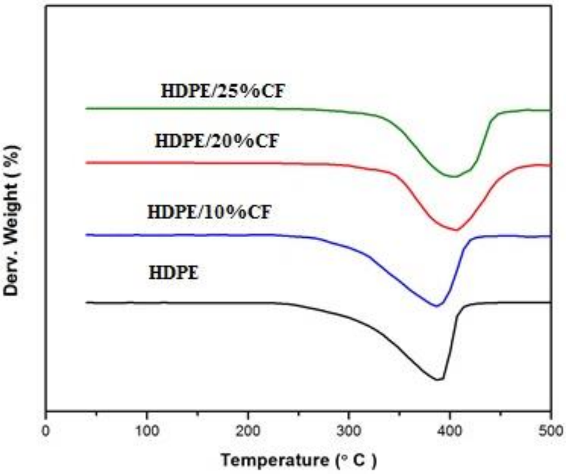

Fig. 2 DTG curves for HDPE and HDPE/CF composites**.**

Table 2 Thermal properties of HDPE and HDPE/CF composites.

Samples	T_{onset} (°C)	T_{10} (°C)	T_{50} (°C)	T_{max} (°C)	Residue at 500°C
HDPE	290	311	368	393	0.5
HDPE/10%CF	319	325	379	396	1.2
HDPE/20%CF	338	350	388	405	3.5
HDPE/25%CF	345	358	401	414	5.7

3.3.Thermal conductivity of composites

Fig. 3 exhibits the thermal conductivity properties of the HDPE/CF composites with different CF contents (10, 20, and 25 wt.%). The thermal conductivity of HDPE composites decreased with the increase of CF content from 10 wt.% to 25 wt.%. Fig. 3 shows that the incorporation of CF loading in HDPE causes a reduction of thermal conductivity and improves its insulation capability. This reduction might have been attributed to higher interactions that occurs between CF and HDPE during the composite preparation. The significant conductivity decreases are observed at 10 wt.%, 20 wt. %, and 25 wt. % as 0.25 w/m.k, 0175 w/m.k, 0.152 w/m.k respectively (neat HDPE conductivity is 0.34 w/m.k). Heat transfer over polymer composites is based on the interfacial thermal conductance of plastic materials and filler. The problem in the case of the neat HDPE is to obtain more interfacial thermal conductance. The thermal conductivity of HDPE composite with 25 wt.% CF is dropped by 52% while the composite with 10 wt.% CF and 20 wt.% CF contents are dropped by 26% and 48.5%, respectively.

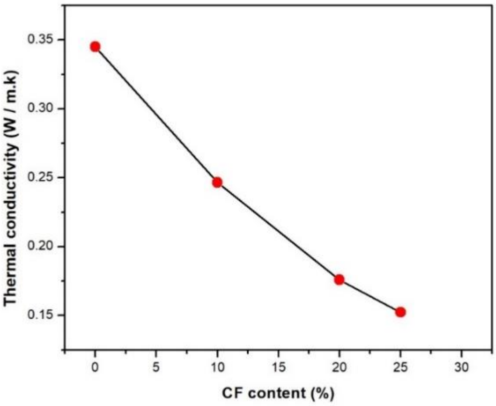

Fig. 3 Thermal conductivity values of neat HDPE and HDPE/CF composites.

3.4. Water absorption of HDPE composite

Fig. 4 displays the long-term water absorption that is plotted based on HDPE/CF composites at room temperature. Water absorption increased with increasing the time of immersion for all samples. Swelling or absorption behavior due to water uptake was examined by using the Eq. (4). The results in Fig. 4 reveals that the HDPE exhibited a lower percentage of water absorption before and after 1000h immersion time. The percentages of water absorption increased with increasing CF contents (10-25 wt.%), because the CF fillers are normally hydrophilic, which can make interactions without difficulty and form hydrogen bonding with water molecules. The results in Fig. 4 showed that the percentage of water absorption is higher for 25 wt. % CF than 10 wt.%, 20 wt. % CF and neat HDPE before and after immersion in different times. The water absorbance percentage before immersion was the highest in HDPE with 25% CF as 1.76%. After the long immersion time (1000h), the percentage of water absorbance increased significantly for HDPE-CF composites as 10.5%, 12.6%, and 14.5% for HDPE with 10%, 20%, and 25% CF respectively. Water absorbance of HDPE after 1000h immersion duration was 7.5%. The obtained results are indicated that the higher contents of CF fillers in the HDPE composites have more water absorbance capabality. The formation of agglomerations decreased while the filler content increased due to the difficulties of producing a homogeneous dispersion between higher loading levels of filler and HDPE.

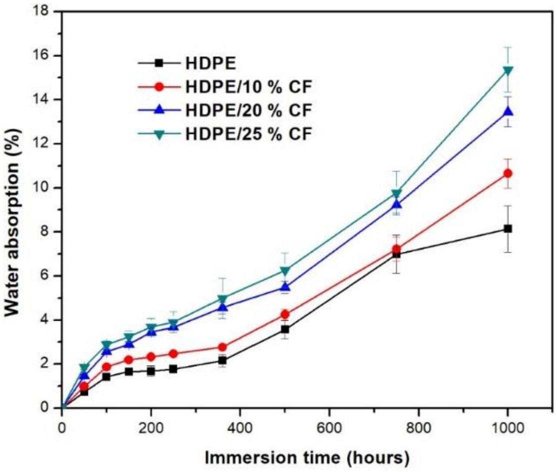

Fig. 4 Water absorption of neat HDPE and HDPE /CF composites with different loading levels.

4. Conclusion

HDPE composites were reinforced with different CF contents as 10%, 20%, and 25%. They were prepared successfully by melt mixing, and their properties were evaluated. The tensile strength, modulus of elasticity, flexural strength, and flexural modulus were completely increased with increasing CF in HDPE. Impact strength reparsed with an increase of CF loading. The improvements in thermal conductivity observed in higher content of CF and increased incorporation of CF into HDPE composites. The water absorption of HDPE increased with the content of CF filler. Addition of CF into the HDPE increased the onset degradation temperature, final decomposition, and higher residual yield. HDPE composites had more thermal stability than that of neat HDPE. Tensile strength was increased for HDPE/25 % CF (37.2 MPa), compared to pure HDPE (23.4 MPa). Strain at break gradually increased from 4.4% for HDPE to 8.6 % for 25% CF in composites. It could be summarized that CF was distributed uniformly in HDPE matrix and the suitable composite was formed. As a result, the optimum content of CF (25 wt. %) improved the mechanical, thermal stability, and physical properties of HDPE material.

Acknowledgments

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