

The Functional and Biodegradation Characteristics of High-Density Poly-ethylene, Poly-caprolactone and Poly-ethylene Maleic Anhydride Composites

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Abstract

The goal of this research is to develop environmental friendly polymer composites in order to reduce the use of current polymers and promote global security. High density poly-ethylene (HDPE) and poly-caprolactone (PCL) composites were mixed with varying amounts of poly-ethylene joined maleic anhydride (PE-g-MA) as a strong compatibilizer. The different composites were prepared using the conventional infusion shaping approach. Mechanical properties were accounted for to have good increase for the diverse compositions and the strength and pliable strain% (stretching) rate at break were improved in comparison to unadulterated HDPE. Examining electron magnifying lens (SEM) morphology revealed that the expansion of PE-g-MA increased the compability and so aided in the achievement of a synergistic mix of superior qualities.

The manure internment test yielded favorable bio-corruption results and demonstrated the fertilizer's ability to enable bio-debasement of various composites, allowing their utilization as key polymers in the assembly of single-use products and also protecting nature and acting as a decent waste administration of HDPE polymer.

Keywords: High density poly-ethylene, poly-caprolactone, poly-ethylene grafted maleic anhydride, bio-degradable, morphological and mechanical.

Introduction

Polymers are important in many industries because of their excellent mechanical, physical and thermal properties. Each year, massive volumes of plastic objects are produced using these polymers. These polymers, such as HDPE, pollute the natural environment around us. Many countries are aiming to shift their plastic usage away from non-biodegradable plastics and towards biodegradable polymers. The majority of researchers have proposed biopolymers and biodegradable polymers as replacements for present polymers.

Reducing the use of existing polymers or non-biodegradable polymers would save the environment and will reduce the consequences^{7,10,26}. Poly-caprolactone (PCL) is prepared via ring-opening polymerization of caprolactone. It is a versatile

aliphatic semi-glasslike poly-ester that has been shown to be miscible with a wide range of polymers. PCL is distinguished by its biodegradable qualities as it is aggressively biodegraded by numerous small animals in various miniature natural settings^{5,24}. Because they are easily available on an industrial scale, PCLs are particularly attractive bio-degradable polymers for mixing with conventional polymers.

PCL is a biodegradable polymer with a strain% of more than 1000% and a tensile strength at break of roughly 32 MPa. These numbers are excessive when compared to a non-biodegradable polymer's strain range of 500-725% and strength at break range of 9.7-17.2 MPa^{1,23}. PCL melts at 60 °C, causing processing difficulties and limiting its application because of its limited softening behavior.

To address this issue in a variety of PCL applications, it may be blended with alternative based polymers such as HDPE which contributes in many plastic applications.

As a result, the purpose of this study is to design relatively bio-degradable composites of HDPE, PCL and PE-g-MA that can bio-corrupt regularly over time, reducing the impact of the manufactured plastics on the surrounded state^{8,11,27}.

Material and Methods

The used HDPE grade (HDPE6070) with a density of 0.960 g/cm³ has a melt flow rate of 7.6 g/10 min at 190°C from Petrochemicals Company (SIDPEC), Egypt. Polycaprolactone with Mwt = 80,000 and melting temperature of 60°C was used, it was supplied by Sigma Aldrich, UK. High density poly-ethylene grafted maleic anhydride grade (Fusabond® E100) with a melt flow rate of 2 g/10min at 190°C, 2.16 Kg and a density of 0.954 g/cm³ was purchased from E.I. DuPont De Nemours and Company Inc.

Samples preparation: Table 1 shows the various composite mix combinations used in this experiment. Materials were combined and prepared in a Blixer 4 robot vehicle at 3000 rpm for 6 minutes. The infusion trim of the different specimens was completed with an Arburg allrounder 221k single screw-infusion shaping machine from Germany.

Mechanical Properties: The HDPE/PCL and PE-g-MA composites were tested using a common testing machine with a load cell of 5 KN (Zwick/z005, Germany) as shown in figure 1.

Table 1
The proposed different compositions

Composite	Poly-ethylene (wt%)	Poly-caprolactone (wt%)	PE-grafted-MA (wt%)
A0	100	0	0
A1	98	1	1
A2	97	1	2
A3	95	1	4
A4	97	2	1
A5	96	2	2
A6	94	2	4
A7	95	4	1
A8	94	4	2
A9	92	4	4

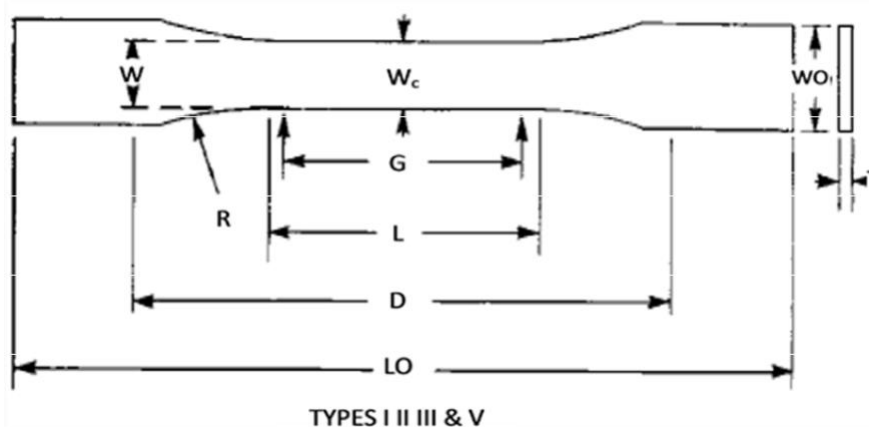


Figure 1: Specimen dimensions (American Standard ASTM D638-08)

All free weight moulded samples, as per ASTM D638-08, were tested at room temperature. The examples were modified prior to testing in lab conditions for 24 hours. The malleable test was performed at a crosshead speed of 20 mm/min under uni-pivotal pressure.

Scanning Electron Microscopy (SEM): The test was used to gather information on how a compatibilizer contributes to the improvement of composite qualities. The JEOL JSM-5300 was used for the test.

Enzymatic degradability: The tested constructions sheets were cut into squares 20 mm in size and 0.5 mm thick, then dried in a vacuum grill at 40 °C to a consistent weight. Each example was placed in a container with 5 ml of phosphate cradle arrangement (pH = 7.2) and 5 ml of chemical (lipase). The pots were brooded for 120 hours at 37 °C. After brooding, it was removed, rinsed with refined water and dried to a consistent weight. The amount of corruption was determined by reducing the rate weight within the chosen time period.

Bio-degradation test: The specimens used were 1 mm thick and formed by pressure forming using a water-powered press as previously shown. The sheets were cut into squares (40 mm 40 mm) and dried to a constant weight in a vacuum

grill at 40°C. The samples, which had a comparable initial shape (for example, a similar surface to introduce to the biodebasement treatment), were coated inside the container containing experienced manure. The fertiliser was kept at room temperature in a 240 litre lab composter (Picture 1) with a constant wind stream rate.

Because of the amount of growth of the manure, the temperature was never entirely above room temperature (25 ± 2) °C. The weight drop rate pointed to the extent of corruption. The amount of corruption was evaluated (with reference to the level of weight decrease). Water showers kept the tests moist in the manure. The concomitant condition determined the rate of weight loss.

$$\% \text{ Weight Loss} = ((W_i - W_f) / W_i) \quad (1)$$

where W_i and W_f are weight before and weight after manure entombment individually.

Results and Discussion

Mechanical properties: The test was performed on all of the prepared composites and excellent HDPE and the yield quality and stretching rate at break esteems were recorded (Table 2).



Picture 1: Bin used for composting system

Table 2
The tensile test results of neat HDPE and its composites

Composite	Tensile strength at yield (MPa)	Elongation at break (%)
A0	25	1090
A1	27	1141
A2	26	1150
A3	26	1120
A4	27	1191
A5	26	1054
A6	26	987
A7	28	1204
A8	27	1083
A9	27	1041

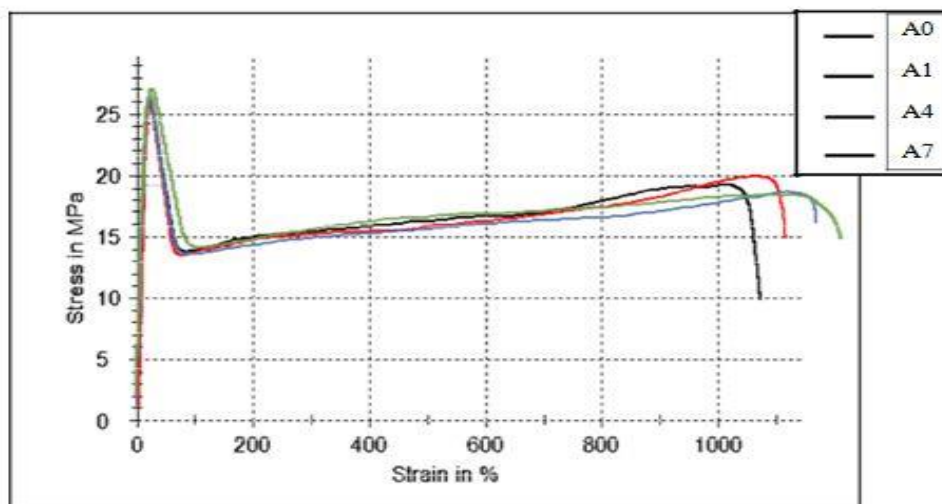


Figure 2: Stress-Strain curves of samples A0, A1, A4 and A7

As shown in figure 2, the expansion of PCL at various rates of 1 wt%, 2 wt%, 4 wt% and PE-g-MA to the HDPE lattice proved to be beneficial in increasing mechanical characteristics. The stiffness of A1, A4 and A7 increased progressively from 25 MPa for HDPE to 28 MPa for A7. The stretching rate at break increased gradually from 1090% for flawless HDPE to 1204% for A7. This enhancement can be attributed to the increased compatibility caused by the use of PE-g-MA as a compatibilizer which improved the miscibility and interfacial grip between PCL and HDPE.

The induced compatibility can be attributed to the interaction of maleic anhydride with the hydroxyl (OH) end gatherings of PCL, which may result in a better interface. The smooth PCL has a high pliability which can significantly impact the extension rate at break and elevate it higher than the perfect HDPE^{2,13,20,21,25,28}.

Scanning electron microscope (SEM): As shown in figure 3, an electron magnifying instrument (SEM) was used to

investigate the cross segment area shape and potential interfacial grip between the HDPE framework, PCL and HDPE-g-MA. The morphology of composites is limited by the preparation circumstances, organisation and polymer concept (interfacial pressure and consistency percentage)^{4,15}. In contrast to the ready composites, which showed reduced homogeneity, HDPE had a homogeneous, smooth and consistent surface.

By increasing the PCL concentration, the homogeneity decreased, indicating poorer compatibility within the composite. The PE-g-MA fuse enhanced the homogeneity bit by bit, implying that the PE-g-MA took its role as a compatibilizer and improved the compatibility between HDPE and PCL. For composites A7, A8 and A9, it is highly evident that the modest increase in the PE-g-MA rate increased the morphology and interfacial binding between the grid portions, which would significantly impact various characteristics^{6,18}.

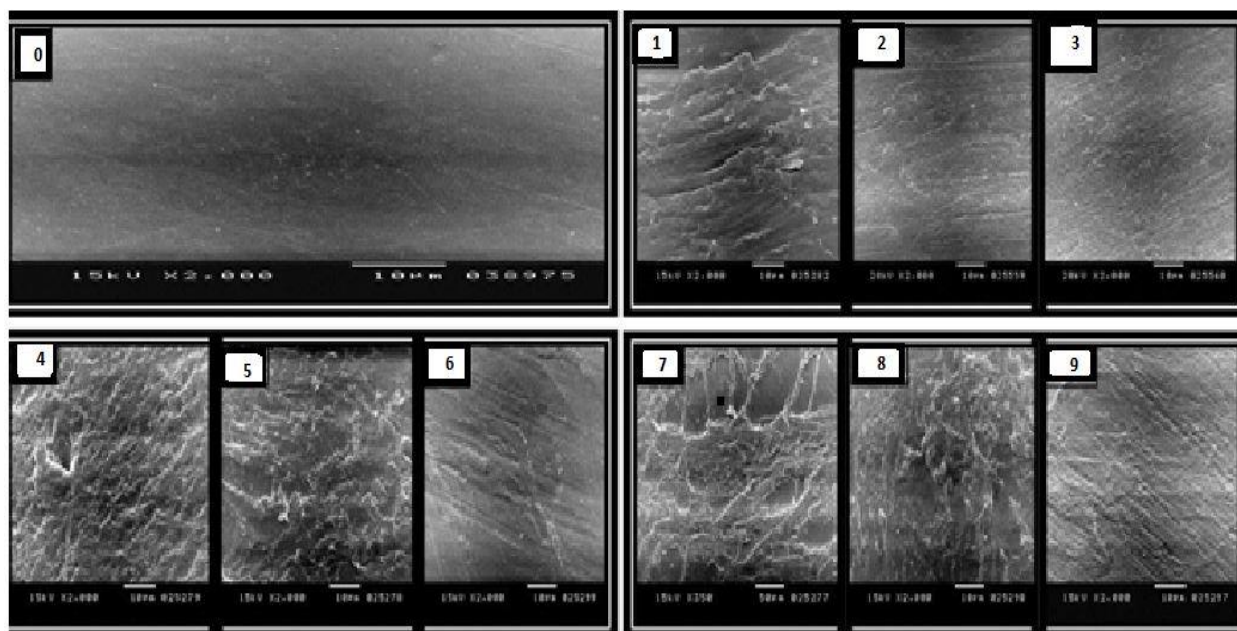


Figure 3: SEM micrographs of HDPE and different composites

Table 3
The % of weight losses with lipase enzyme after 120 hours

Composite	HDPE	PCL	PE-g-MA	Weight Loss %-Lipase
A0	100	0	0	0
A1	98	1	1	0.8
A2	97	1	2	0.8
A3	95	1	4	0.9
A4	97	2	1	1.7
A5	96	2	2	1.7
A6	94	2	4	2.1
A7	95	4	1	3.8
A8	94	4	2	4.2
A9	92	4	4	4.3

Table 4
The % of weight losses of HDPE and other composites during bio-degradation

Composite	Wt. loss% 1 Month	Wt. loss% 2 Months	Wt. loss% 4 Months
A0	0	0	0
A1	0.01	0.06	0.09
A2	0.01	0.07	0.09
A3	0.01	0.07	0.10
A4	0.02	0.08	0.10
A5	0.03	0.08	0.12
A6	0.03	0.08	0.13
A7	0.04	0.09	0.14
A8	0.05	0.09	0.16
A9	0.05	0.10	0.18

Enzymatic degradability: Table 3 shows the weight decrease with lipase catalyst after 120 hours. Various lipases may degrade poly-caprolactone in a very short period of time. This was the reason why a lipase enzyme was used in this study. Lipases are endo-type proteins that randomly corrupt the ester obligations of macromolecular chains. It is claimed that the instrument of ester bond hydrolysis frames an acyl-protein junction. The acyl-compound middle of the road is subsequently hydrolyzed, releasing free unsaturated fat while recovering protein^{17,19,22}. It was revealed that the weight loss increased as the PCL material increased from 1% to 4% which might be due to the protein activity that increases with the increasing ester concentration.

Bio-degradation test: Plastics biodegrade well under manure conditions due to their characteristics and the optimal development circumstances of fertiliser microorganisms^{9,14}. It is critical to note that only bio-corruption is assessed with no consideration given to UV degradation, which is also relevant if HDPE corruption occurs. By increasing the poly-caprolactone content and the time factor, the weight loss rate increased. As shown in table 4, the weight loss increased gradually over four months from 0.09 wt% for test A1 containing 1 wt% PCL to 0.14 wt% for test A7 containing 4 wt% PCL. The combination of PE-g-MA improved the presentation of bio-debasement and increased the power of PCL material to stimulate biodegradability in the samples. For example, when the PE-g-MA concentration increased from 1% to 4%, the weight reduction rate increased from 0.14 wt% to 0.18 wt% for tests A7 and A9.

The presence of PCL and PE-g-MA triggered biodegradability inside HDPE. PCL is a biodegradable polyester that is impacted by microbial activity in fertiliser. The initiation of microbial-corruption of PCL chains might explain the enhanced degradation of composites in comparison to HDPE. As the PCL fixation spread, so did the bio-corruption. Furthermore, the incorporation of PE-g-MA into the network improved the compatibility of HDPE and PCL and enhanced the PCL bio-degradable influence on the composite which increased the weight reduction rate. By

increasing the PE-g-MA concentration, moisture absorption and growth are increased, resulting in faster biodegradation. This appears in other tests that get equivalent results^{3,12,16}.

Conclusion

The introduction of low-cost PCL into the HDPE framework altered its characteristics. The mechanical characteristics increased significantly with the addition of PE-g-MA as a compatibilizer which enhanced the compatibility within the composite and influenced the interfacial bond. The bio-deterioration evaluation test yielded remarkable results after four months in relation to the low PCL rates used in this investigation.

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