The Physical and Mechanical Properties of Polymer Composites Filled with Fe Powder

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ABSTRACT: In this study, the effect of Fe powder on the physical and mechanical properties of high density polyethylene (HDPE) was investigated experimentally. HDPE and HDPE containing 5, 10, and 15 vol % Fe metal–polymer composites were prepared with a twin screw extruder and injection molding. After this, fracture surface, the modulus of elasticity, yield and tensile strength, % elongation, Izod impact strength (notched), hardness (Shore D), Vicat softening point, heat deflection temperature (HDT), melt flow index (MFI), and melting temperature (T_m) were determined, for each sample. When the physical and mechanical properties of the composites were compared with the results of unfilled HDPE, it was found that the yield and tensile strength, % elongation, and Izod impact strength of HDPE decreased with the vol % of Fe. As compared with the tensile strength and % elongation of unfilled HDPE, tensile strength and % elongation of 15 vol % Fe filled HDPE were lower, about 17.40% and 94.75% respectively. On the other hand, addition of Fe into HDPE increased the modulus of elasticity, hardness, Vicat softening, MFI, and HDT values, such that 15 vol % Fe increased the modulus of elasticity to about 48%. J Appl Polym Sci 99: 2438–2442, 2006

Key words: composite; fillers; microstructure; mechanical properties; thermal properties

INTRODUCTION

Metal–polymer composites exhibit the properties of both metals and polymers and have been the subject of extensive research for the last two decades. Various kinds of polymers and polymer matrix composites reinforced with metal particles have a wide range of industrial applications, because of their low density, high corrosion resistance, ease of fabrication, and low cost.[1–3]

The physical and mechanical properties of the composite materials depend on the volume fraction of the fillers and additives, such as metal or ceramic, on the form of them, such as powder or fiber, and on the interfacial compatibility between the metal particles and the matrix.[4] Such fillers and additives are introduced to the system to improve thermal and electrical conductivity, and to stiffen the matrix.[3]

Electrical,[5] thermal,[6–8] and mechanical properties[9–11] of particulate-filled polymer composites were investigated in a number of different works. Zois et al. studied the electrical properties of polymer composites filled with Fe-powder.[5] Tavman reported that the thermal conductivity of aluminum powder-filled high density polyethylene (HDPE) composites increased, and tensile strength and elongation at break decreased with the vol % of Al, which was attributed to the discontinuities in the structure.[7] Ghosh and Maiti reported that tensile modulus, strength, and % elongation decreased with silver concentration in polypropylene.[10] Bigg introduced silicon carbide, aluminum flakes, and stainless steel fibers into thermoplastic polymers and showed that the modulus of elasticity was a function of the concentration of fillers, and tensile strength of the composite depended strongly on the strength of the interfacial bond between the polymer and the filler.[11]

In this article, 5, 10, and 15 vol % of Fe powder, as fillers and HDPE as polymer matrix, were used to prepare the metal–polymer matrix composites. The effect of iron particles on the thermal and mechanical properties of HDPE was investigated.

EXPERIMENTAL

Metal–polymer matrix composites were prepared by using the following materials: HDPE, known as Petilen YY, was obtained from PETKIM, Petrokimya Holding A.S., Turkey. Iron powder, known as Ancorsteel 1000HP, was obtained from Hoeganaes, USA. The purity of Fe was 99.75%, and the average particle size was 50 μm. In addition, the morphology of iron powder was irregular.

To investigate the effect of iron particles on the physical and mechanical properties of the composite system, 5, 10, and 15 vol % of Fe were introduced into HDPE, using a twin screw extruder (Maris-TM40MW-

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TABLE I
The Melting Temperature, HDT, and Vicat Softening Point Values of HDPE and HDPE-Fe Composite Systems

Sample	T_m (°C)	HDT (°C)	Vicat softening point (°C)
HDPE	147.75	42.4	126.3
HDPE (5 vol % Fe)	151.66	45.6	128.9
HDPE (10 vol % Fe)	177.00	46.2	129.8
HDPE (15 vol % Fe)	147.43	50.1	128.3

TABLE II
The MFI Values of HDPE and HDPE- Fe Composite Systems

Sample	MFI (g/10 min)
HDPE	5.18
HDPE (5 vol % Fe)	6.29
HDPE (10 vol % Fe)	6.40
HDPE (15 vol % Fe)	6.71

Maris America Corp., Baltimore, USA). The extrusion temperature, pressure, and screw speed were 180–230°C, 20 bar, and 24 rpm respectively. To prepare the samples for thermal and mechanical tests, the following injection conditions were used: injection temperature was 210–230°C, injection pressure was 40 bar, dwelling time in mold was 10 s, and cooling water temperature was 40°C.

Tensile test samples were prepared according to the ISO 294 standards, by using an Arburg injection molding machine (Arburg GmbH Co., Lossburg-Germany). Tensile tests were conducted according to the ISO 527.2, at a crosshead speed of 50 mm/min. Izod impact test (notched) was done according to the ISO 180 standards, by using a Zwich type impact machine (Zwich GmbH, Ulm-Germany). Melt flow index (MFI) values were obtained according to the ASTM D 1238 standards, with Zwick test equipment. To determine the melting temperature, DSC studies were carried out by using SETERAM DSC 131 (Scientex Pty. Ltd. Victoria-Australia). Heat deflection temperature (HDT) and Vicat softening point values of the composites were obtained by using a CEAST 6505 equipment (Ceast SPA, Pianezza-Italy). To characterize the surface morphology, samples were coated with carbon, about 40 Å in thickness, by using POLARON SC 7640 (Gala Instrumente GmbH, Bad Schwalbach-Germany). After this, the coated samples were studied by using FIE Srion SEM, operated at 15 kV.

RESULTS

Melting temperature, HDT, and Vicat softening point values of HDPE and Fe-HDPE polymer composite

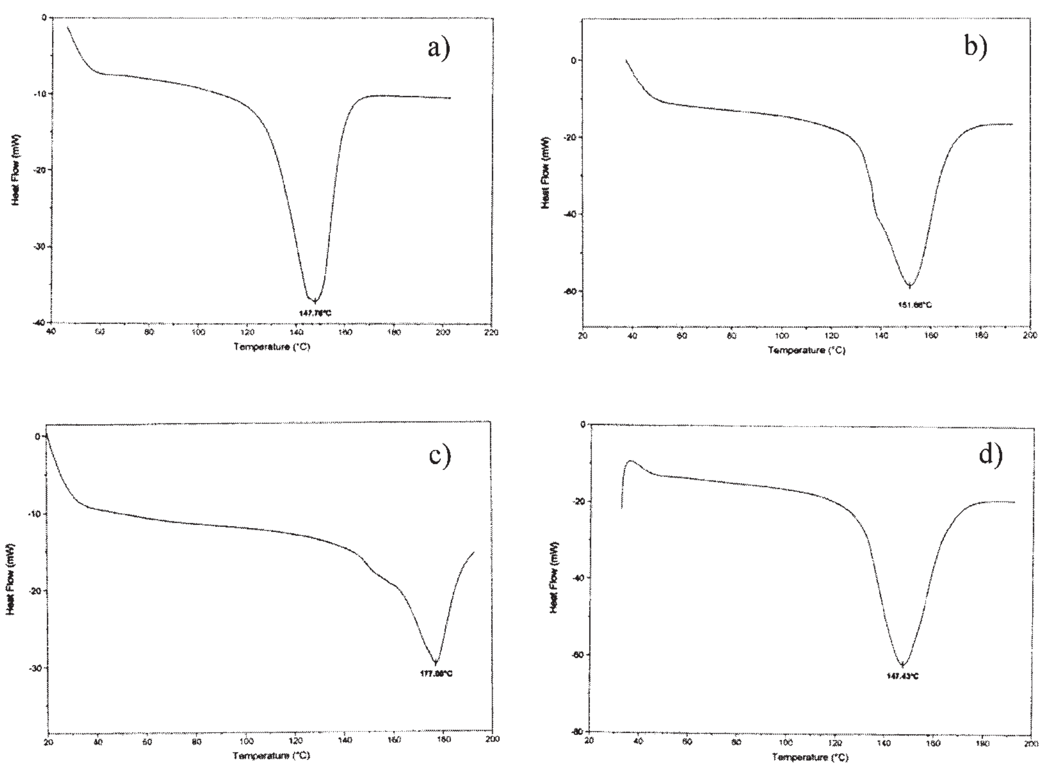

Figure 1 DSC curves of (a) HDPE, (b) HDPE containing 5 vol % Fe, (c) HDPE containing 10 vol % Fe, and (d) HDPE containing 15 vol % Fe.

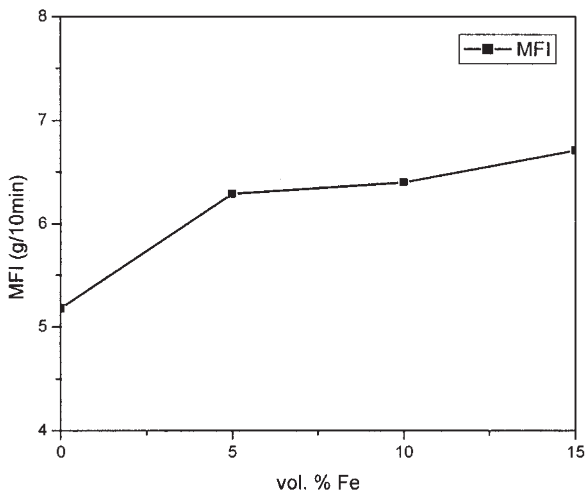

Figure 2 The MFI values of HDPE and HDPE-Fe polymer composite.

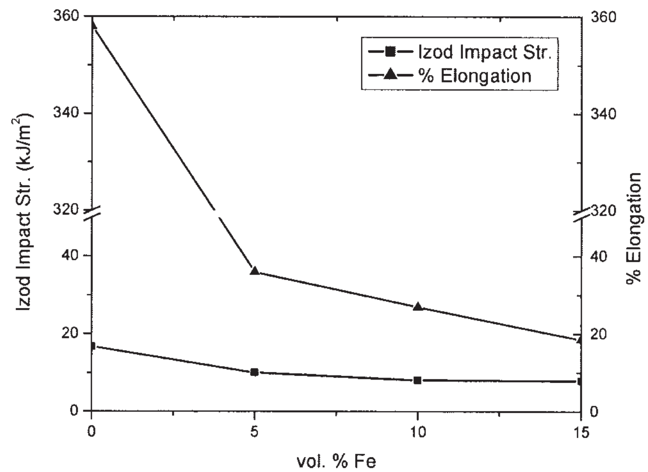

Figure 3 The effect of Fe particles on Izod impact strength (notched) and % elongation.

systems studied here are given in Table I, and the measured DSC curves are shown in Figure 1. As seen from the table, Addition of Fe powder in HDPE increased melting temperature, HDT, and Vicat softening point of HDPE. When the vol % of Fe in HDPE was increased from 10 to 15, a drop in melting temperature and Vicat softening point values was seen.

The measured MFI values of the samples are given in Table II and also plotted in Figure 2. From the table, it is seen that the MFI values increased with the vol % of Fe in HDPE, such that the rate of increase in MFI value was sharper for the composite containing 5 vol % Fe.

The mechanical properties of HDPE and Fe-HDPE polymer composites are listed in Table III. As shown in the table, the introduction of Fe particles into HDPE resulted in a sharp decrease in Izod impact strength of the HDPE, such that 5 vol % of Fe reduced Izod impact strength of HDPE to about 40%. Similar effect was observed in % elongation. Addition of 5 vol % of Fe into HDPE reduced % elongation to about 90%. When the vol % of Fe was increased to 10 and 15, Izod notched impact strength, and % elongation values decreased slowly. Figure 3 shows the rate of change in both Izod impact strength and % elongation. In addition, Fe particles caused a gradual decrease in both the yield and tensile strength of HDPE. Reduction in tensile strength and Izod impact strength of the composites are most likely due to the presence of Fe particles that may act as stress raiser, and due to weak interfacial adhesion between the fillers and the matrix. On the other hand, Fe particles improved the modulus of elasticity and hardness of HDPE.

The effect of Fe on the yield and tensile strength and hardness can be seen from Figure 4. The ratio of hardness to the modulus of elasticity as a function of vol % of Fe is given in Figure 5. As shown in the figure, decrease in the ratio of the hardness to the modulus of elasticity, with the vol % of Fe, indicates that Fe addition improved the wear resistance of HDPE.

The micrographs taken from the fracture surfaces of HDPE and HDPE-Fe composite samples are shown in Figure 6. The arrows on the figures indicate Fe particles and the dimples left by the particles after fracture. This indicates that the bond between the polymer and particles is weak. Large particles indicate that some of the particles coalesced into a single particle during processing of the composites. As seen from the figure, addition of Fe particles resulted in porous structure. This can be seen clearly from Figure 6(c).

TABLE III
The Mechanical Properties of HDPE and HDPE-Fe Polymer Composites

Mechanical property	HDPE	HDPE (5 vol % Fe)	HDPE (10 vol % Fe)	HDPE (15 vol % Fe)
Izod notched imp. strength (kJ/m^2)	16.73	10.06	8.09	7.93
Hardness (shore D)	55.33	57.33	58.00	58.83
Modulus of elasticity (MPa)	284.43	373.95	388.36	420.95
Tensile strength (MPa)	22.62	21.02	20.64	18.55
Yield strength (MPa)	22.46	21.00	20.59	18.15
% elongation	358.03	35.94	26.92	18.79

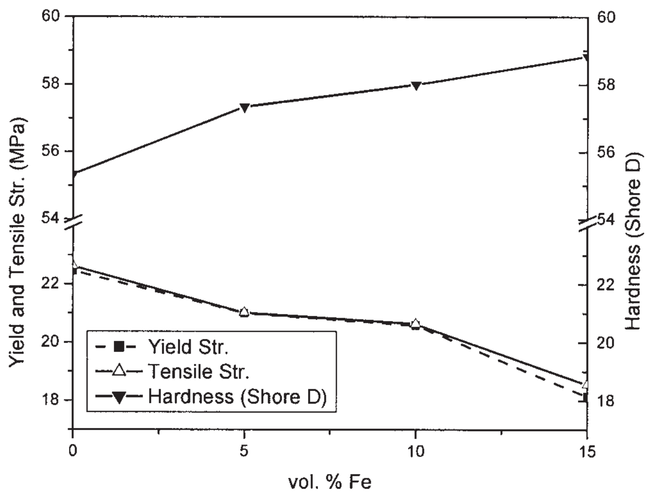

Figure 4 The effect of Fe on the yield and tensile strength and hardness (Shore D) of HDPE.

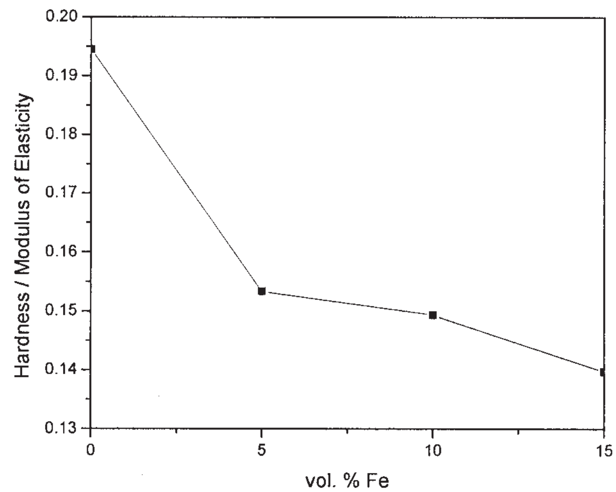

Figure 5 The ratio of hardness (Shore D) to the modulus of elasticity as a function of vol % of Fe.

CONCLUSIONS

In this article, the physical and mechanical properties of HDPE and HDPE-Fe polymer composites were investigated. It was found that introduction of Fe particles into HDPE reduced the yield and tensile strength, % elongation, and Izod impact strength (notched) of HDPE. Rate of decrease in Izod impact strength and % elongation was large, when 5 vol % Fe was first added into HDPE. Increasing the vol % of Fe from 5 to 10 and 15, a slower decrease in Izod impact strength and % elongation was observed. In addition, a gradual decrease in the yield and tensile strength of the composites was found by increasing the vol % of Fe in HDPE. As compared with the tensile strength and % elongation of unfilled HDPE, tensile strength and % elonga-

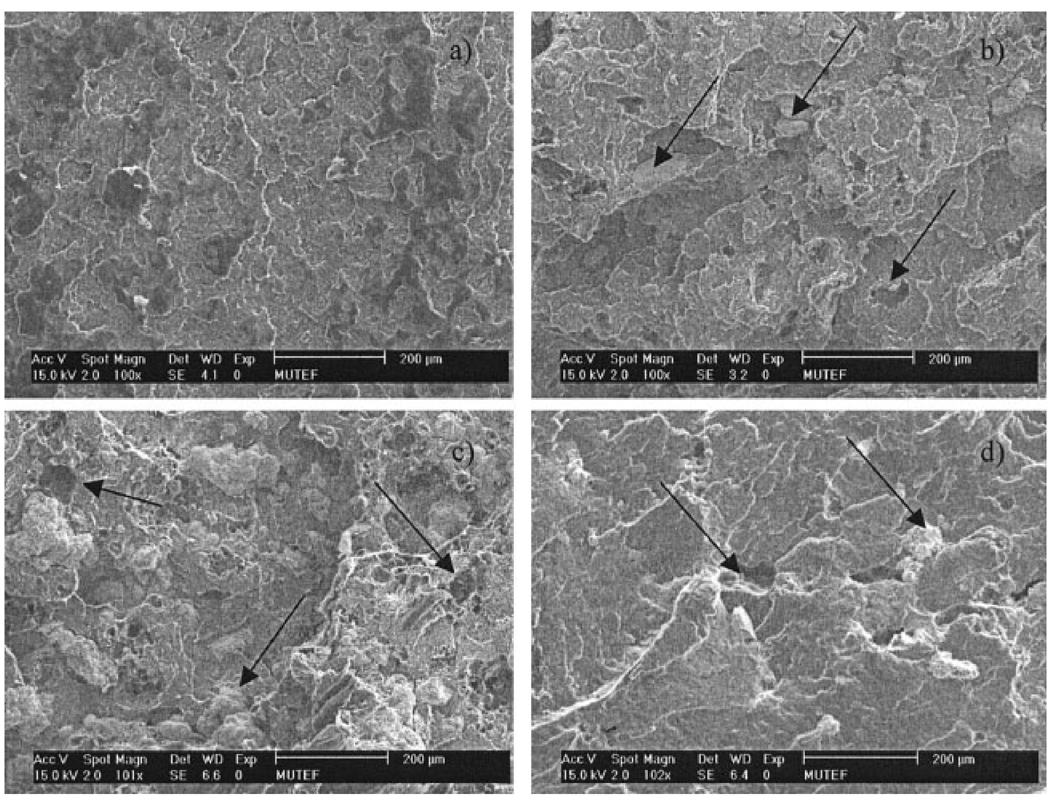

Figure 6 SEM micrographs taken from the fracture surfaces of HDPE and HDPE-Fe composites: (a) HDPE, (b) HDPE containing 5 vol % Fe, (c) HDPE containing 10 vol % Fe, and (d) HDPE containing 15 vol % Fe.

tion of 15 vol % Fe-filled HDPE were lower, about 17.40% and 94.75% respectively. On the other hand, addition of Fe increased the modulus of elasticity, hardness, Vicat softening point, MFI, and HDT values of the HDPE, such that 15 vol % Fe increased the modulus of elasticity to about 48%.

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