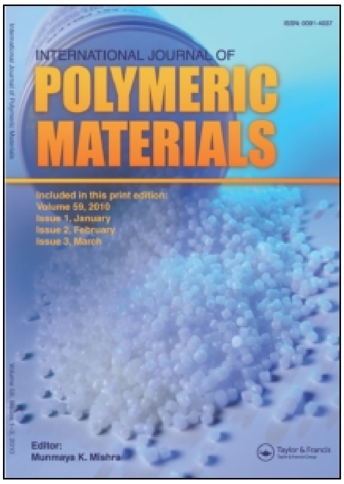

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Münir Taşdemır[a]; H. Özkan Gülsoy[a]
[a] Technical Education Faculty, Marmara University, Istanbul, Turkey

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Mechanical Properties of Polymers Filled with Iron Powder

Münir Taşdemır
H. Özkan Gülsoy
Technical Education Faculty, Marmara University, Istanbul, Turkey

Mechanical properties of metal-polymer matrix composites were investigated experimentally. High density polyethylene (HDPE), polypropylene (PP), and polystyrene (PS) were used as the polymer matrix and Fe powder in 5, 10, and 15 vol% was used as the metal. The modulus of elasticity, yield and tensile strength, % elongation, Izod notched impact strength, Shore D hardness, and fracture surfaces of the composites were determined. It was found that vol% Fe reduced the Izod impact strength of HDPE much more than that of PP and PS, while Fe powder increased the hardness of HDPE more than that of PP and PS. Among the composites, PS-Fe composites had higher yield, tensile strength and modulus of elasticity than HDPE-Fe and PP-Fe composites. However, % elongation of PS-Fe composites was lower than that of the other composites. In addition, HDPE- and PP-based composites exhibited ductile type fracture, while PS-Fe composites exhibited brittle type fracture.

Keywords: composite, fillers, fracture, microstructure, mechanical properties

INTRODUCTION

For the last two decades, advanced polymer composites became attractive structural materials for new structures such as automobiles, bridges, and airplanes [1]. Composite materials are made up of two or more materials to obtain unique properties. For many advanced composites, thermoplastics and thermoset plastics are used as matrix and fibers, and powdery metals/ceramics are used as reinforcement material. Various kinds of fillers and additives are introduced into

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Address correspondence to Münir Taşdemir, Technical Education Faculty, Marmara University, Goztepe 34722, Istanbul, Turkey. E-mail: munir@marmara.edu.tr

the polymer matrix to improve thermal [2–4] and electrical conductivity [2,5,6], and mechanical properties [3,4,7–9].

Mechanical properties of 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 [6] between the finer particles and the matrix. Various kinds of polymers and polymer matrix composites reinforced with metal particles have a wide range of industrial applications such as heaters, electrodes, positive temperature coefficient [10], and composites with thermal stability at high temperature [11]. These engineering composites are desirable due to their low density, high corrosion resistance, ease of fabrication, and low cost [4,5,8].

In this article, 5, 10 and 15 vol% of Fe powder as filler and HDPE, PP, and PS as polymers were used to prepare metal-polymer matrix composites. Then, the effect of Fe powders on the mechanical properties of the polymers was investigated experimentally.

EXPERIMENTAL

Metal-polymer matrix composites were prepared by using the following materials: HDPE known as Petilen YY, PP known as Petoplen, and PS known as Petren were obtained from PETKIM, Petrochemical Holding A.S., Turkey. Iron powder known as Ancorsteel 1000-C was obtained from Hoeganaes, USA. The purity of Fe was 99.75% and the average particle size was 50 micron. The morphology of the iron powder was irregular.

To investigate the effect of iron particles on the mechanical properties of the composite systems, 5, 10, and 15 vol% of Fe were introduced into HDPE, PP, and PS using a twin screw extruder (Maris-TM40MW-Maris America Corporation, Baltimore, USA). The extrusion temperature, pressure and screw speed were 180–230°C, 20 Bar, and 24 rpm respectively. To prepare the samples for 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 sec 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 cross-head speed of 50 mm/min. Izod notched impact tests were done according to the ISO 180 standards by using a Zwick type impact machine (Zwick GmbH, Ulm-Germany). To characterize the surface morphology, samples were coated with carbon about 40 Å in thickness by using POLARON SC 502 (Gala Instrument

GmbH, Bad Schwa Bach, Germany). After that, the coated samples were studied by using a JSM-5410 LV JOEL SEM (Joel, Peabody, M.A.).

RESULTS

Izod impact strength and hardness of the polymers and metal-polymer composites are given in Table 1.

As seen from Table 1, unfilled HDPE shows higher Izod impact strength than unfilled PP and PS. After introduction of Fe powders to the polymers, Izod impact strength of the composites started decreasing with the vol% Fe powder. The reduction in Izod impact strength of HDPE, PP, and PS containing Fe powder is given in Figure 1. From Figure 1, it is seen that Fe powder significantly reduces the Izod impact strength of HDPE while it does not have a sharp effcet on the Izod impact strength of PS.

On the other hand, the hardness of the polymers increased with the vol% Fe. The % increase in hardness as a function of the Fe content is given in Figure 2.

From the figure, the hardness of the polymers increases sharply with the addition of 5 vol% Fe. After that the rate of change in hardness of composites does not change much.

The mechanical properties obtained from stress-strain curves are given in Table 2 and selected stress-strain curves are given in Figure 3.

As is shown in Table 2, Fe powders had a negative effect on the yield and tensile strength and % elongation, and a positive effect on the modulus of elasticity of the polymer composites.

TABLE 1 Izod Impact Strength and Hardness of the Polymers and Composites

Materials	Izod impact strength (kJ/m^2)	Hardness (Shore D)
HDPE	16.73	15.33
HDPE (5 vol% Fe)	10.06	57.33
HDPE(10 vol% Fe)	8.09	58.00
HDPE(15 vol% Fe)	7.93	58.83
PP	8.80	60.00
PP (5 vol% Fe)	8.73	61.50
PP(10 vol% Fe)	8.16	62.23
PP(15 vol% Fe)	5.83	63.00
PS	1.66	82.20
PS (5 vol% Fe)	1.53	83.05
PS (10 vol% Fe)	1.49	84.21
PS (15 vol% Fe)	1.42	85.06

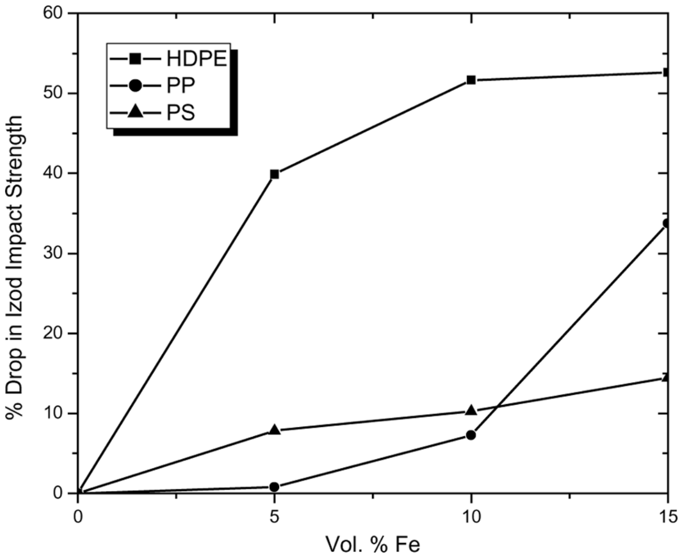

FIGURE 1 The effect of vol% Fe on % drop in Izod impact strength of the polymer composites.

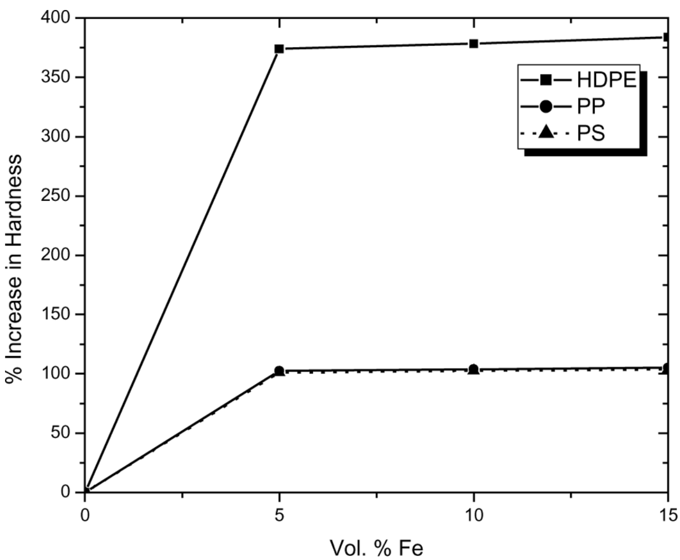

FIGURE 2 The effect of vol% Fe on the hardness of the composites.

TABLE 2 The Modulus of Elasticity, Yield and Tensile Strength, and % Elongation of the Polymers and the Metal-Polymer Composites

Materials	The modulus of elasticity (MPa)	Yield strength (MPa)	Tensile strength (MPa)	% Elongation
HDPE	284.43	22.46	22.62	358.03
HDPE (5 vol% Fe)	373.95	21.00	21.02	35.95
HDPE (10 vol% Fe)	388.36	20.59	20.64	26.92
HDPE (15 vol% Fe)	420.95	18.15	18.55	18.79
PP	255.31	27.27	28.18	45.13
PP (5 vol% Fe)	294.20	25.83	26.33	26.35
PP (10 vol% Fe)	388.79	20.47	21.19	24.96
PP (15 vol% Fe)	400.80	16.58	20.08	20.71
PS	952.37	42.11	43.12	4.05
PS (5 vol% Fe)	1119.29	41.83	42.93	3.69
PS (10 vol% Fe)	1242.00	40.80	42.09	3.53
PS (15 vol% Fe)	1271.82	32.31	32.77	3.98

It was found that the mechanical properties of HDPE- and PP-containing Fe powder given in Table 2 were comparable. Unfilled PS-and Fe-filled PS composites had higher yield and tensile strength and a modulus of elasticity than HDPE and PP composites. However, the % elongation of PS-based composites was lower than that of HDPE- and PP-based composites. Selected micrographs taken from the fracture surfaces of the polymers and metal-polymer composite samples are shown in Figure 4. 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. As it is seen from the figure, HDPE, PP, HDPE-Fe and PP-Fe composites exhibit ductile type fracture, while PS and PS-Fe composites exhibit brittle type fracture.

DISCUSSION AND CONCLUSION

Some mechanical properties of HDPE-Fe, PP-Fe, and PS-Fe metal-polymer composites were studied experimentally, and unfilled HDPE, PP, and PS were used as a reference. As compared to the unfilled HDPE, PP, and PS, it was found that yield and tensile strength, % elongation, and Izod notched impact strength of the polymers decreased, while the modulus of elasticity and Shore D hardness increased by increasing the vol% Fe in the polymers. In more detail, vol% Fe had more negative effect on Izod impact strength of HDPE

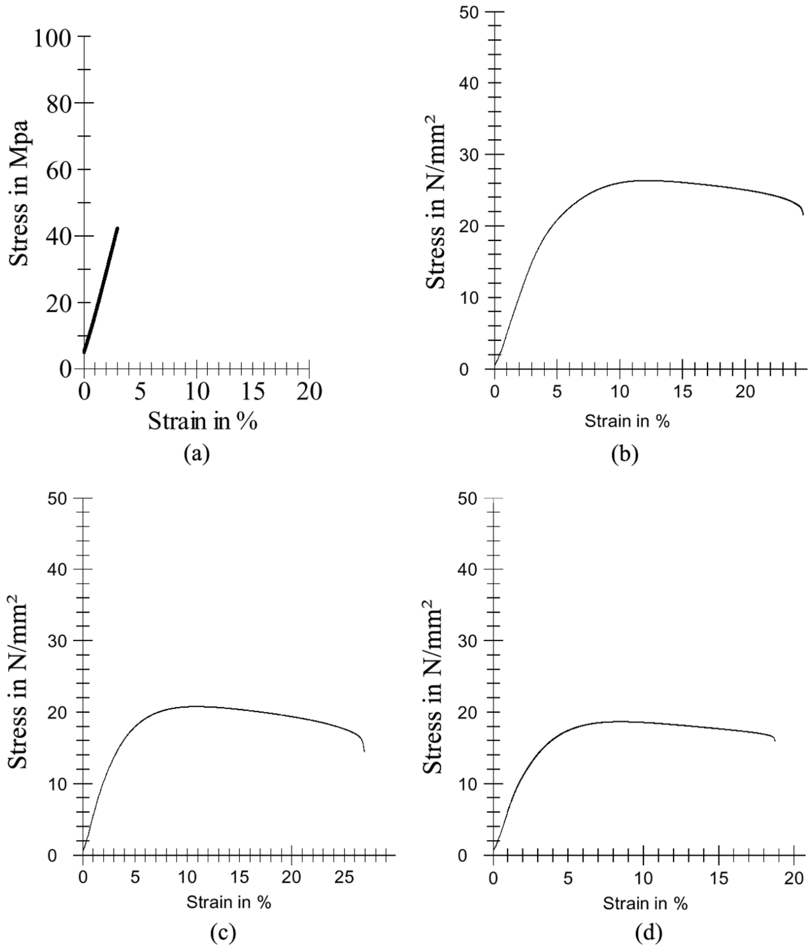

FIGURE 3 Stress-strain curves: a) unfilled PS, b) PP-5 vol% Fe, c) HDPE-10 vol% Fe, and d) HDPE-15 vol% Fe.

than that of PP and PS. However, the addition of Fe powder increased the hardness of HDPE more than that of PP and PS. Among the polymer composites, PS-Fe metal-polymer composites had higher tensile yield strength and modulus of elasticity than HDPE-Fe and PP-Fe composites. On the other hand, % elongation of PS-Fe composites was lower than that of the other composites. In addition, from the fracture surfaces it was seen that HDPE- and PP-based metal-polymer composites exhibited ductile type fracture, while PS-Fe composites exhibited brittle type fracture.

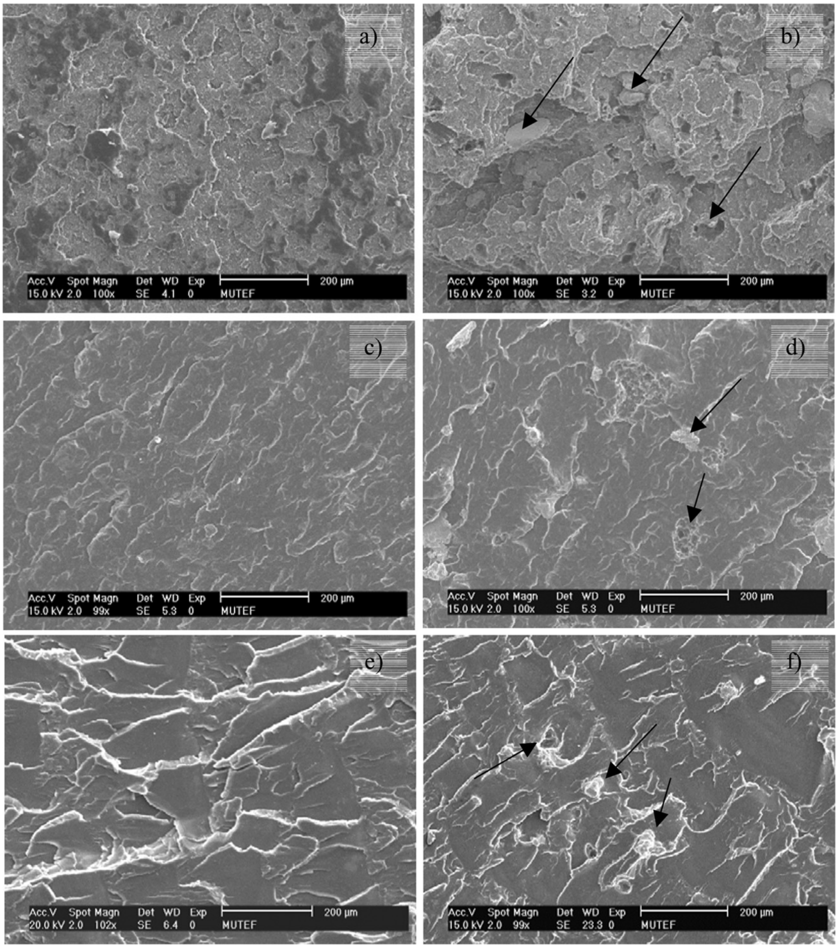

FIGURE 4 SEM micrographs taken from the fracture surfaces of: a) unfilled HDPE, b) HDPE-5 vol% Fe, c) unfilled PP, d) PP-5 vol% Fe, e) unfilled PS, and f) PS-5 vol% Fe.

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