

Simultaneous Toughening of PPO/HIPS/Glass Fiber Reinforced Composites with Thermoplastic Rubbers

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ABSTRACT: Simultaneously reinforced and toughened PPO/HIPS/SEBS/glass fiber (GF) 60/40/5/30 composites were successfully prepared with GF as reinforcing agent and SEBS as toughener. The formulation of PPO/HIPS/SEBS/GF quaternary composites was stepwise optimized by evaluating the effect of GF and SEBS on the processing, mechanical and thermal properties of the composites. The synergistic effects of GF reinforcement and elastomer toughening are attributed to high performance PPO/HIPS/SEBS/GF composites. Among the four elastomers studied, SEBS exhibited as effective toughener for PPO/HIPS matrix and the resulted PPO/HIPS/SEBS/GF composites presented a good combination of mechanical and thermal properties. The optimized PPO/HIPS/SEBS/GF 60/40/5/30 quaternary composites displayed a tensile strength of 123.6 MPa, a bending strength of 149.7 MPa, an unnotched impact strength of 46.6 KJ/m² and a heat distortion temperature of 148.9°C. © 2013 Wiley Periodicals, Inc. *J. Appl. Polym. Sci.* **2014**, *131*, 40299.

KEYWORDS: composites; properties and characterization; elastomers

Received 22 July 2013; accepted 14 December 2013

DOI: 10.1002/app.40299

INTRODUCTION

Polymer composites reinforced with glass fiber (GF) constitute a current area of interest in material research.^{1,2} The reinforcement offers an attractive way to improve the mechanical properties of thermoplastics, mainly attributed to the good mechanical properties of GF. The mechanical properties of the composites are partially determined by the interfacial adhesion between polymer resin and GF. Besides, the rheological, thermal and processing properties are the main considerations of the resulted multicomponent composites.^{3–5} Polymer composites are generally formulated via melt-blending to obtain tailor-made cost-effective materials with synergistic properties of individual components. The resulting composites, however, may exhibit inferior properties than polymer resins, due to the immiscibility and incompatibility among components in the composites. To achieve balanced mechanical properties, polymer composites can be effectively reinforced with surface modified GF^{1–3} or toughened with thermoplastic rubbers.^{6–10}

Poly(2,6-dimethyl-1,4-phenylene oxide) (PPO) is an important engineering plastic, featuring high mechanical strength, high heat resistance, and good dimensional stability. The broad application of PPO, however, is limited due to its natural brittleness, poor processability, and low solvent resistance.⁴ Great research efforts

have thus been made to modify PPO with polymers like polyamide,^{4,5,7} polypropylene,⁸ and polystyrene (PS).^{9,10} The inherent properties of PPO and modifying polymers, such as nylon 6 and PS suggest that their blends should combine the advantages from individual components, affording useful blends with improved solvent resistance and processability.¹⁰ However, PPO/polyamide blends generally show deteriorated impact and tensile strength due to their immiscibility^{4,5} and poor interfacial adhesion.¹¹ To improve the interfacial adhesion and mechanical properties of PPO blends, effective toughening agents including poly(ethylene-1-octene) (POE),⁵ ethylene-propylene-diene monomer (EPDM),¹² styrene-butadiene-styrene (SBS),⁶ styrene-ethylene-butylene-styrene (SEBS),⁶ and their derivatives (e.g., SEBS-*g*-maleic acid anhydride and EPDM-*g*-maleic acid anhydride)¹³ are often used for PPO binary blends^{6,13} or tertiary blends.^{4,5,8,14,15}

As one of the few polymers miscible with PPO, high impact polystyrene (HIPS) can form blends with PPO in a wide range of blending ratios.⁹ In addition, PPO/HIPS blends are commercially available from General Electric Company as Noryl resin. However, their still relatively low impact strength has to be improved using suitable elastomers for high-performance blends.^{11,15–18} Meanwhile, the mechanical and thermal properties of resins can be improved with GF.¹⁹ To our best knowledge,

there are few studies on the simultaneous toughening and reinforcement of PPO/HIPS blends using elastomers and GF. Picchioni et al. observed increased toughness when blending PPO/PS (50/50) with elastomers like SBS and SEBS.²⁰ The mechanical properties and heat resistance PPO/PS composites were further increased using GF,^{21–23} where GF was pretreated with suitable silane coupling agents (SCAs) to promote the adhesion between GF and polymeric resin.²⁴ The interfacial bonding strength between fibers and the polymer matrix can be controlled by the coupling agents.¹ By reacting silane hydroxy with both GF and polymers, SCAs promote the phase adhesion between GF and polymer matrices. For GF-reinforced polyarylene ether nitrile (PEN) composites, γ -triethoxysilylpropylamine (KH550) generated more effective interfacial adhesion than γ -glycidoxypropyltrimethoxysilane (KH560) and γ -methacryloxypropyltrimethoxysilane (KH570).¹⁹ The reason is explained by the larger interactions between PEN and KH550 induced by the greater polarity of the amino-functional group of KH550 in comparison to the other two kinds of SCAs. Liu et al. reported a reinforced Noryl blend with GF and thermotropic liquid-crystalline polymer (TLCP), where TLCP was thought to reduce fiber breakage by altering the orientation of GF to favor its reinforcement.²⁵

In continuation to our previous research in developing toughened polymer blends/composites,^{16–19,26–29} we wonder if the PPO/HIPS blends can be simultaneously toughened with elastomers and reinforced with GF. We report herein the preparation of simultaneously GF-reinforced and rubber-toughened PPO/HIPS/elastomer/GF quaternary composites for the first time. The mechanical properties, heat resistance and morphology of the as-prepared composites were investigated. SEBS demonstrated as an effective impact modifier for PPO/HIPS/GF composites. The results may provide direct guidance for the simultaneous toughening and reinforcement of commercially available Noryl resin with SEBS and GF.

EXPERIMENTAL

Materials

PPO was obtained from GE Plastics and had an intrinsic viscosity of 0.4 dL/g measured in chloroform at 25°C. Commercial grade of HIPS (HI 425) with a 4.5 g/10 min melt flow index (MFI) (at 200°C under 5 kg load) was supplied by KUMHO Petrochemical Co. (Korea). POE (Engage 8150) with a MFI of 0.5 g/min (at 190°C under 2.16 kg load) was procured from Dow Elastomers (Wilmington/Delaware, USA). EPDM (EP57P) with an ethylene content of 66 wt % was supplied by Japan synthetic rubber Co. (JSR, Japan). Supplied by Yanshan Petrochemical Co. (Beijing, China), SBS (1401-1) had a MFI of 1 g/10 min (at 230°C under 2.16 kg load) and an S/B weight ratio of 38/62. SEBS (YH-503) with a polystyrene content of 33 wt % was procured from Yueyang Petrochemical Co. Ltd. (SINOPEC, China).

E-glass fibers used for reinforcement had 3 mm average length of and 13 μ m average diameter and were obtained from Beijing Xingwang Glass Co. (China). The fibers were heat cleaned for 4 h at 500°C before use. γ -Triethoxysilylpropylamine (KH550) was procured from Dow Corning under the trade name Z-6011. GFs were treated with KH550 in solution and cured for 10 h at

120°C. These surface modified GFs were then dried at 50°C under vacuum for 6 h prior to blending.

Preparation of PPO/HIPS/GF and PPO/HIPS/Elastomer/GF Composites

All polymer components were dried in a vacuum oven at 75°C for 24 h. The dried components and surface-modified glass fibers were physically premixed according to formulation before being feeding to extruder. All polymer composites were melt-mixed in a co-rotating twin-screw extruder ($\Phi = 20$, $L/D = 40$, Kunshan Kexin Plastic Engineering Company, China). In the extrusion step, the barrel temperature profile was set as 270, 290, 300, 300, and 280°C from hopper to die and a screw speed of 150 rpm was used. The extrudates were immediately quenched in water and subsequently cut into pellets. All pellets were dried in 140°C oven for 4 h. The standard regular bars for bending strength and impact strength measurement and dumbbell-shaped specimens for tensile properties testing were injection-molded using a JPH-120 injection-molding machine. The temperature profile for injection molding was set as 300, 290, 280, and 270°C from hopper to die. The mold temperature was maintained at 100°C. All specimens were annealed at 150°C for 0.5 h before cooling to room temperature for testing.

Mechanical Properties and Heat Resistance

The notched or unnotched Charpy impact strengths were determined with a XJJ-5 pendulum impact tester at 23°C according to GB/T 1043-1993. The dimension for the specimens is 120 \times 15 \times 10 mm³. A notch (3.3 mm deep) was made for the notched impact strength testing. The average value of six to eight measurements was reported for each blend composition. The tensile strength and bending strength were measured as per GB/T 1040-1992 and GB/T 9341-2000 methods, respectively. The measurements were carried out on an Instron-3211 universal tensile tester. The crosshead speed of 50 mm/min was set for tensile tests and 2 mm/min for bending measurements. The values of both mechanical parameters were calculated as average over six to eight specimens for each composition.

The heat distortion temperature of composite was measured on an XRW-300 tester according to GB/T 1634-1979 with a load of 1.8 kPa at the heating rate of 50°C/h. The melt flow rate of composites was measured according to GB/T 3682-2000 under 300 \pm 0.2°C with a load of either 5.0 or 10.0 kg.

Scanning Electron Microscopy

The morphological characteristics were examined using scanning electron microscopy (SEM). Prior to examining, the samples were fractured along the direction perpendicular to the melt flow direction in liquid nitrogen. The fracture surface was then coated with a thin layer of gold. The fracture morphology was observed with a JEOL JSM-6360LV scanning electron microscopy, using an acceleration voltage of 20 kV.

RESULTS AND DISCUSSION

Effect of GF Surface Modification

For PPO/HIPS/GF composites, GF was surface treated with 3-triethoxysilylpropylamine (KH550) (0.5 wt % of GF) before melt-blending. As similarly observed for GF-reinforced PEN composites,¹⁹ the surface treatment of GF with KH550 results

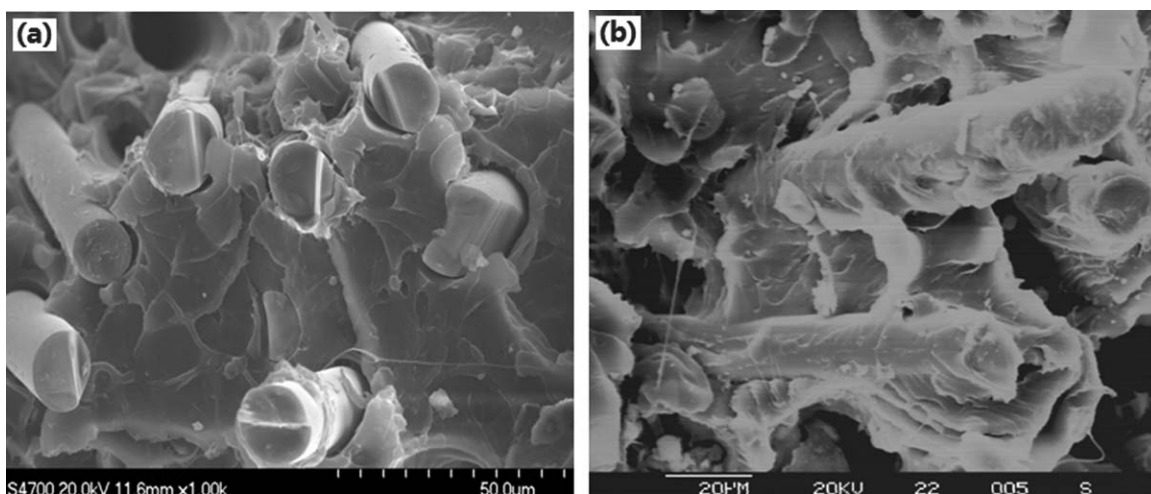


Figure 1. SEM images of impact fractured surface of PPO/HIPS/GF 70/30/30 with (a) untreated GF and (b) KH550 treated GF.

in a better wetting of fibers into PPO/HIPS resin, leading to an improved interfacial adhesion. The enhanced interfacial adhesion can be clearly observed from the SEM images of impact-fractured surfaces for the composites. As shown in Figure 1, the interface between PPO/HIPS and GF is very clear for composites with un-treated GF. The fracture surface is very smooth, with cavities formed after GF fibers pulled out of PPO/HIPS matrix. In contrast, with surface-treated GF, the fiber surface is coarse and resin is conglutinated on it, implying effective interfacial adhesion promoted by KH550. The promotion of interfacial adhesion between PPO/HIPS matrix and GF is consistent with previous studies in glass-fiber reinforced polymer composites.^{1,2,19}

The substantially improved interfacial adhesion (as observed in Figure 1) in turn increased the mechanical properties of PPO/HIPS/GF composites. As summarized in Table I, PPO/HIPS/GF composites exhibited greatly increased tensile and bending strengths, while 10% decrease in impact strength. The heat resistance, represented by heat distortion temperature, improved with 23.1 wt % addition of *E*-type GF. The improvement in mechanical properties of composites can be explained by the strengthened interfacial adhesion between PPO/HIPS matrix and GF, where GF can help to absorb the impact energy when subjected to external forces.⁷ For this reason, all GF-reinforced PPO/HIPS composites prepared in the following studies were

all fabricated with surface-modified GF, unless specially explained.

Effect of GF Loading on the Mechanical Properties of PPO/HIPS/GF Composites

PPO/HIPS 60/40 blend was employed to study the effect of GF on the mechanical properties of PPO/HIPS/GF composites. The melt processability of PPO/HIPS/GF composites was evaluated with the melt flow index at $300 \pm 0.2^\circ\text{C}$ under the load of 5 and 10 kg, respectively. The MFI of pure PPO was determined as 0.97 under the load of 10 kg, while 21.73 for PPO/HIPS 60/40 blend. As depicted in Figure 2(a), the addition of GF leads to the decrease in MFI for PPO/HIPS/GF composites due to larger melt viscosity. The decrease rate in MFI, however, was found to slow down after 10 wt % GF addition. Even at 40 wt % addition of GF, the composites still exhibited a MFI of 10.6 under 10 kg load, which is over ninefold higher than that of pristine PPO resin.

The heat resistance of PPO/HIPS/GF composites is evaluated using heat distortion temperature (HDT). GF acts as physically crosslinked network in composites, which could limit the thermal movement of polymer chains and prevent the elastic and plastic deformation of polymeric matrices.²⁰ The variation of composite HDT with GF content is depicted in Figure 2(b). It is evident that the addition of GF can dramatically improve the

Table I. Surface Modification of GF on the Mechanical Properties of PPO/HIPS/GF Composites

Composite	Tensile strength (MPa)	Bending strength (MPa)	Unnotched impact strength (KJ/m ²)	Heat distortion temp. (°C)
PPO	72.8 ± 1.6	84.3 ± 1.3	31.8 ± 0.9	191.2 ± 0.7
PPO/HIPS 60/40	75.0 ± 3.7	82.3 ± 1.2	36.5 ± 1.4	140.2 ± 0.3
PPO/HIPS/GF 60/40/30 ^a	119.4 ± 4.6	143.9 ± 2.1	32.0 ± 1.2	144.8 ± 0.4
PPO/HIPS/GF 60/40/30	132.2 ± 6.5	153.4 ± 2.4	35.2 ± 2.3	151.5 ± 0.6

^a GF without surface modification with KH550 (0.5 wt % of GF).

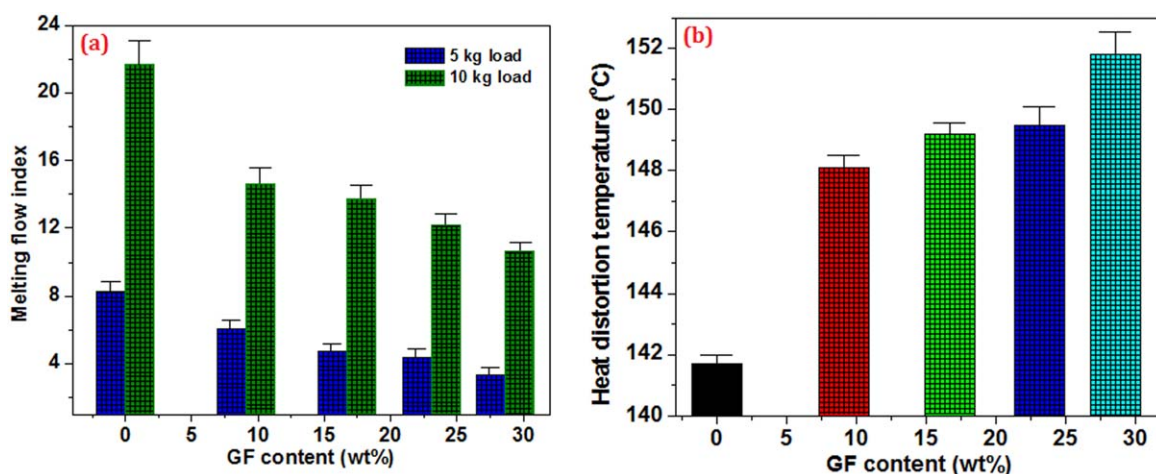


Figure 2. Effect of GF content on (a) the melting flow index and (b) the heat distortion temperature of PPO/HIPS/GF (60/40/30) composites. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

composite HDTs, where 9.1 wt % addition of GF lead to 6°C enhancement in HDT for PPO/HIPS blends. The HDT of PPO/HIPS/GF composites increased gradually with increased GF content, with 4°C enhancement when GF content was increased from 9.1 to 28.6 wt %.

The reinforcement of GF on PPO/HIPS/GF composite can be elucidated by the improvement of tensile strength (Figure 3) and bending strength (Figure 4). As shown in Figure 3, the tensile strength of PPO/HIPS/GF composite increased with the addition of GF before a local maximum reaches at 23.1 wt %. A further increase in GF content leads to a decreased tensile strength. This phenomenon may be explained with the counterbalance of increased surface fracture energy and increased sizes of voids or GF aggregates with the addition of GF.³⁰ When GF content is lower than 9.1%, the good adhesion (Figure 1) between GF and polymer matrix improves the strain transport to GF till GF fibers break when their strength are exceeded. When GF content increases form 9.1% to 23.1%, the reinforcement effect surpasses the inner crack effect because such factors lead to longer crack propagation path, with the fiber drawn

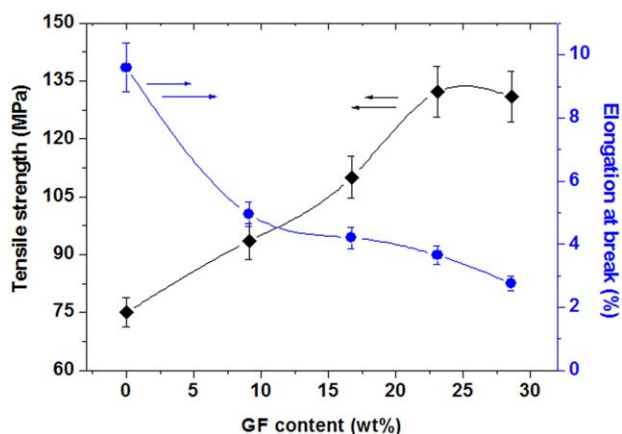


Figure 3. Effect of GF content on (a) the tensile strength and (b) the elongation at break of PPO/HIPS/GF composites. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

from polymeric matrices playing a main role.³¹ As a consequence, the composites achieve greatly improved tensile strength, indicated by a 76% enhancement in tensile strength (from 75 to 132 MPa) with 23.1 wt % addition of GF for PPO/HIPS/GF 60/40/30 blends. Similar behavior is also found for the bending strength. As shown in Figure 4(a), PPO/HIPS/GF 60/40/30 composites showed the highest bending strength of 152 MPa, an 87% enhancement in comparison to PPO/HIPS 60/40 blends (85 MPa). The improvement in bending strength of GF-reinforced PPO/HIPS composites may be explained by the impregnation of high-strength GF in PPO/HIPS matrix with strong interfacial adhesion. With GF content increased over 23.1 wt %, the decrease in tensile strength and bending strength may be attributed to the aggregation and disordered orientation of GF, indicated by the significantly increased melt viscosity of PPO/HIPS/GF composite with GF content [Figure 2(a)]. Consequently, both tensile strength and bending strength of polymer composites decreased with GF content.²⁰

As known, GF reinforcement often leads to a dramatic reduction of the ductility (evaluated by elongation at break and impact strength) of polymer composites.^{1,7} This is reflected in the elongation at break of the composites (Figure 3). The elongation at break of PPO/HIPS/GF composites decreased drastically by ~43% with 9.1 wt % addition of GF, while a slower reduction was observed with further increase of GF content from 9.1 to 28.6 wt %. The impact strength behaved quite differently. As depicted in Figure 4(b), the impact strength of PPO/HIPS/GF composites increased firstly with the addition of GF, reached a local maximum at 16.7 wt % GF, and decreased continuously with further increment of GF content. A close look at the values of the impact strength, PPO/HIPS/GF composites (with GF% \leq 23.1 wt %) exhibited higher impact strength than PPO/HIPS blends. The improvement of impact strength increased with GF addition may be explained by the higher external energy dissipated by GF as the fibers broke.

Formulation Optimization of PPO/HIPS/GF Composites

By fixing GF content (23.1 wt %), PPO/HIPS weight ratio was further optimized in order to achieve a good combination of

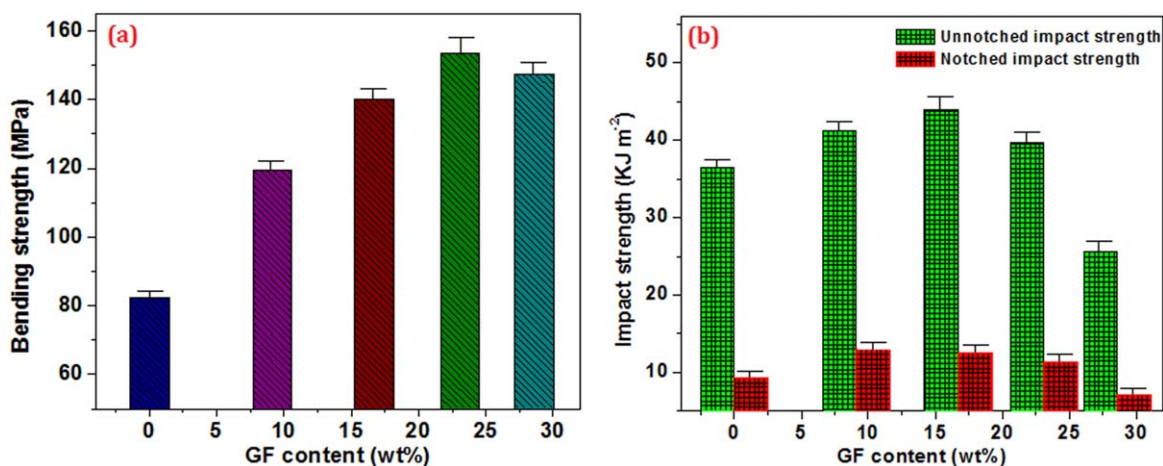


Figure 4. Effect of GF content on (a) the bending strength and (b) the impact strength of PPO/HIPS/GF composites. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

mechanical properties for PPO/HIPS/GF composites. The mechanical properties and heat resistance of PPO/HIPS/GF composites were examined, with data summarized in Table II. As shown, PPO/HIPS/GF composites exhibited obviously decreased tensile strength and HDT with the increase in HIPS content. The impact strength (both notched and unnotched) of the composites, however, firstly increased with HIPS content, reached a local maximum at 46.1 wt % HIPS, and decreased with further increase of HIPS content. All composites with no more than 38.5 wt % HIPS addition (PPO/HIPS/GF 50/50/30) induced over onefold enhancement in notched impact strength in comparison to pure PPO resin. It is noted that the addition of HIPS led to slow decrease in both tensile strength and bending strength, i.e., 13 and 5.5% drop observed when HIPS content increased from 30 to 70 ppr in PPO/HIPS/GF composites.

The decreased stiffness of PPO/HIPS/GF with the addition of HIPS may be explained with the low E -modulus and strength of HIPS. As discussed above, HIPS exhibits certain affinity with surface-treated GF (Figure 1). When increasing the addition of HIPS, it partially encapsulated or coated the GF rather than simply existed as separate domains in bulk matrix. This encapsulation reduces stress concentrations at particle–polymer interface, leading to better impact performance, but also resulting in lower E -moduli.³² The decreased E -modulus and strength of HIPS induce lower stiffness when suffering to tensile or bending loading.

Considering both mechanical and thermal properties, HIPS content of PPO/HIPS/GF composites can be fixed in the range of 23.1–38.5 wt %. For cost consideration, PPO/HIPS/GF 60/40/30 composite was selected as the model system for further toughening study.

Mechanical Properties of PPO/HIPS/Elastomer/GF Composites

The GF-reinforced PPO/HIPS/GF 60/40/30 composite was further toughened using 10 wt % EPDM, POE, SBS, and SEBS elastomers as impact modifiers. EPDM, POE, SBS, and SEBS are widely used for plastic toughening.^{5,6,11,15,16,20,21} The data of mechanical properties and heat resistance for PPO/HIPS/elastomer/GF composites are summarized in Table III. It is clear that all quaternary composites exhibited increased impact strength but decreased stiffness and heat distortion temperature. Among them, SEBS stands out as the most effective toughener. When compared with PPO/HIPS/GF composites, PPO/HIPS/SEBS/GF 60/40/10/30 composite presented a slight decrease in tensile (7% loss) and bending strength (4% loss), but a significant improvement in impact strength (by 54% for notched and 32% for unnotched one). This may be due to the better compatibility of SEBS or SBS with PPO/HIPS blends than POE and EPDM.

The difference in the mechanical properties of four PPO/HIPS/elastomer/GF composites can be explained with the morphology of impact-fracture surface (Figure 5). For linear polyolefin-

Table II. Effect of HIPS Content on the Mechanical Properties of PPO/HIPS/GF Composites

Polymeric composites	Tensile strength (MPa)	Bending strength (MPa)	Unnotched impact strength (KJ/m ²)	Notched impact strength (KJ/m ²)	Heat distortion temp. (°C)
PPO/HIPS/GF 70/30/30	135.8 ± 7.2	152.4 ± 2.1	32.8 ± 1.8	11.6 ± 0.3	168.7 ± 0.6
PPO/HIPS/GF 60/40/30	132.2 ± 6.5	153.4 ± 2.4	35.2 ± 2.3	11.4 ± 0.3	151.5 ± 0.5
PPO/HIPS/GF 50/50/30	130.4 ± 3.6	145.3 ± 1.8	36.4 ± 2.8	13.6 ± 0.6	144.2 ± 0.3
PPO/HIPS/GF 40/60/30	125.5 ± 2.4	143.7 ± 1.2	38.8 ± 3.1	14.1 ± 0.9	130.1 ± 0.2
PPO/HIPS/GF 30/70/30	118.2 ± 1.8	144.0 ± 1.6	32.1 ± 1.5	9.3 ± 0.1	123.2 ± 0.1

Table III. Mechanical Properties of PPO/HIPS/GF Composites and the Elastomer Toughened PPO/HIPS/GF Composites

Polymeric composites	Tensile strength (MPa)	Bending strength (MPa)	Unnotched impact strength (KJ/m ²)	Notched impact strength (KJ/m ²)	Heat distortion temp. (°C)
SEBS YH-503 ^a	25	6	–	–	170
PPO/HIPS/POE/GF 60/40/10/30	77.6 ± 0.1	105.0 ± 0.2	21.2 ± 0.4	13.2 ± 0.6	149.1 ± 0.3
PPO/HIPS/EPDM/GF 60/40/10/30	100.2 ± 0.4	123.2 ± 0.6	32.4 ± 1.5	14.5 ± 0.9	148.5 ± 0.3
PPO/HIPS/SBS/GF 60/40/10/30	120.3 ± 0.9	136.5 ± 1.1	43.9 ± 1.8	15.0 ± 1.2	143.2 ± 0.1
PPO/HIPS/SEBS/GF 60/40/10/30	122.6 ± 1.3	146.7 ± 1.5	46.3 ± 2.5	17.6 ± 1.4	147.8 ± 0.2

^aSEBS YH-503 data are provided by the supplier.

based POE and EPDM, their compatibility with benzene-ring containing PPO and HIPS is poor.^{4,5} Therefore, they are dispersed as droplets in PPO/HIPS matrix, as shown in Figure 5(a,b). Cavitations are clearly seen in the fracture surface of composites, which are thought to be largely responsible for the enhancement of impact strength of the composites. These cavitations were observed when POE or EPDM domains were deformed after impact tests. As mentioned above, POE or EPDM domains act as extra stress concentrators to absorb the impact deformation energy, facilitating the shear yielding of

PPO/HIPS matrix. However, for notched impact fracture, the impact deformation energy absorbed by POE or EPDM to initiate the fracture is lower than that for pure PPO/HIPS/GF composites, leading to lower notched impact strength.

The enhanced toughness of PPO/HIPS/SEBS/GF and PPO/HIPS/SBS/GF composites can be explained by the better compatibility of SEBS (or SBS) with PPO/HIPS matrix, as observed in SEM image [Figure 5(c,d)]. Because SEBS (or SBS) is miscible to both PPO^{6,11,13} and PS,^{16,17} the morphology of both

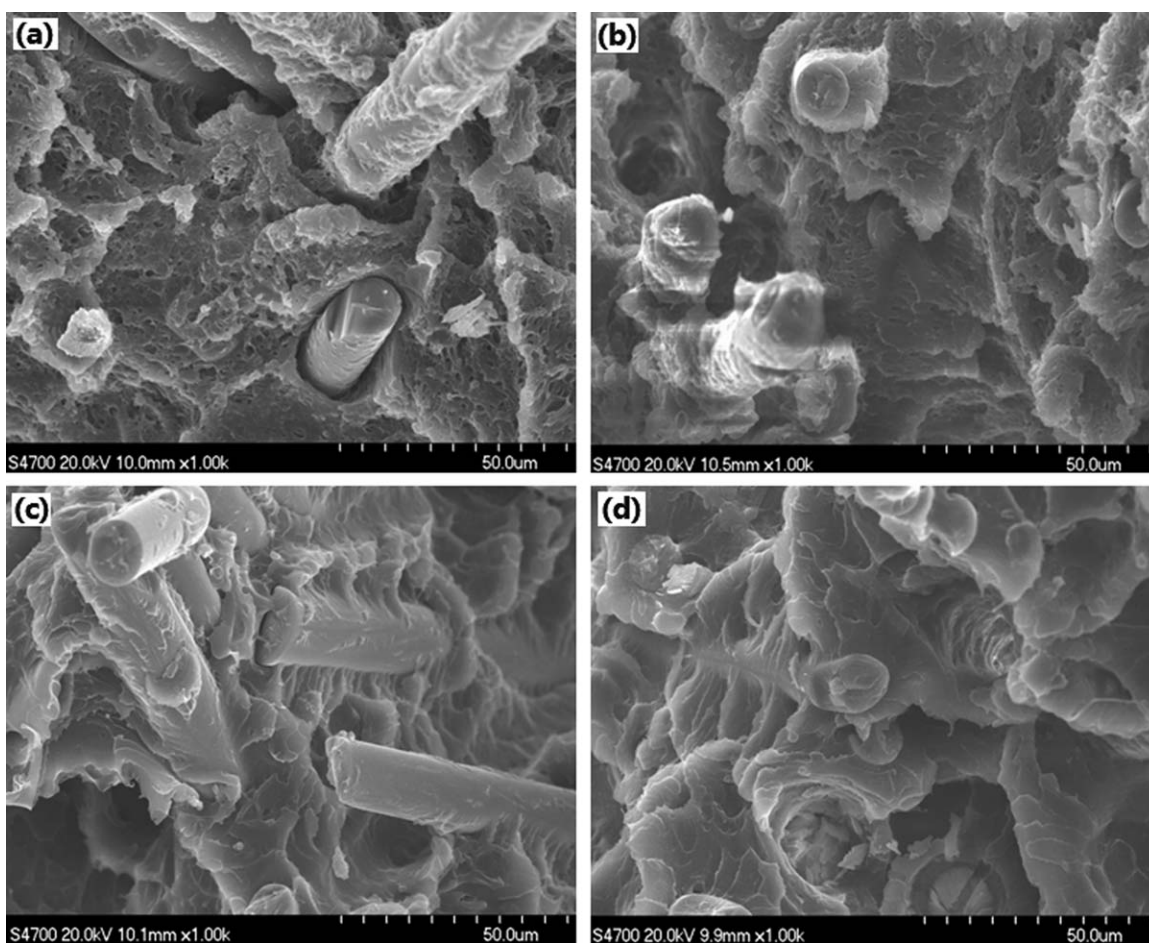


Figure 5. SEM micrographs of PPO/HIPS/elastomer/GF (60/40/10/30) composites toughened by elastomer (a) POE, (b) EPDM, (c) SBS, and (d) SEBS.

PPO/HIPS/SEBS and PPO/HIPS/SBS ternary blends exhibit a miscible matrix, in which are embedded the elastomer particles of PB of HIPS (with salami structure) and particles of SEBS [Figure 5(d)] or SBS [Figure 5(c)].¹⁹ In this case, rigid GFs were tightly bound to polymer resin and arranged in the proper orientation, facilitating the transfer and distribution of the applied load among GF. Thus, more impact deformation energy was absorbed by GF to initiate the shear yielding of polymer matrix.

A careful comparison of the data in Table III, one can find that PPO/HIPS/SEBS/GF composites presented better mechanical and thermal properties than SBS-toughened one. SEBS was thus selected as the impact modifier for PPO/HIPS/GF 60/40/30 composite for the following study.

Mechanical Properties of PPO/HIPS/SEBS/GF Composites

The effect of SEBS on the mechanical properties and heat resistance of PPO/HIPS/SEBS/GF composites was further investigated. As shown in Figure 6(a,b), SEBS toughened PPO/HIPS/SEBS/GF composites exhibited typical elastomer-toughening behavior, i.e., both tensile and bending strength of the composites decreased with the addition of SEBS. The decrease in composites' stiffness may be explained with the even lower E -modulus and strength of SEBS than HIPS. Hence, PPO/HIPS/GF/SEBS presented much faster drop in tensile and bending strength when increasing the content of SEBS than HIPS did for PPO/HIPS/GF composites (Table II).

As shown in Figure 6(c), PPO/HIPS/SEBS/GF composites exhibited improved impact strengths than PPO/HIPS/GF composites. PPO/HIPS/SEBS/GF 60/40/15/30 composite (10.3 wt % SEBS) showed the highest impact strength (47 KJ/m² for unnotched and 20 KJ/m² for notched one). Overall, PPO/HIPS/SEBS/GF composites with SEBS content in the range of 3.7–10.3 wt % exhibited much higher toughness than PPO/HIPS/GF composites.

PPO/HIPS/SEBS/GF composites showed slow decrease in HDT with the addition of SEBS, with only 3°C decrease in HDT observed for PPO/HIPS/SEBS/GF composite after addition of 18.8 wt % SEBS [Figure 6(d)]. The slow decrease in HDT with SEBS addition may be attributed to the good heat resistance of SEBS. With a saturated backbone, SEBS itself has a HDT as high as 170°C.

Based on the above discussion, we can assess PPO/HIPS/SEBS/GF as 60/40/5/30 as the optimal formulation, exhibiting a tensile strength of 123.6 MPa, a bending strength of 149.7 MPa, an unnotched impact strength of 46.6 KJ/m², and a heat distortion temperature of 148.9°C.

CONCLUSIONS

In summary, PPO/HIPS blends have been simultaneously reinforced and toughened with surface-modified GF and SEBS. The optimal formulation for GF-reinforced PPO/HIPS/GF composite

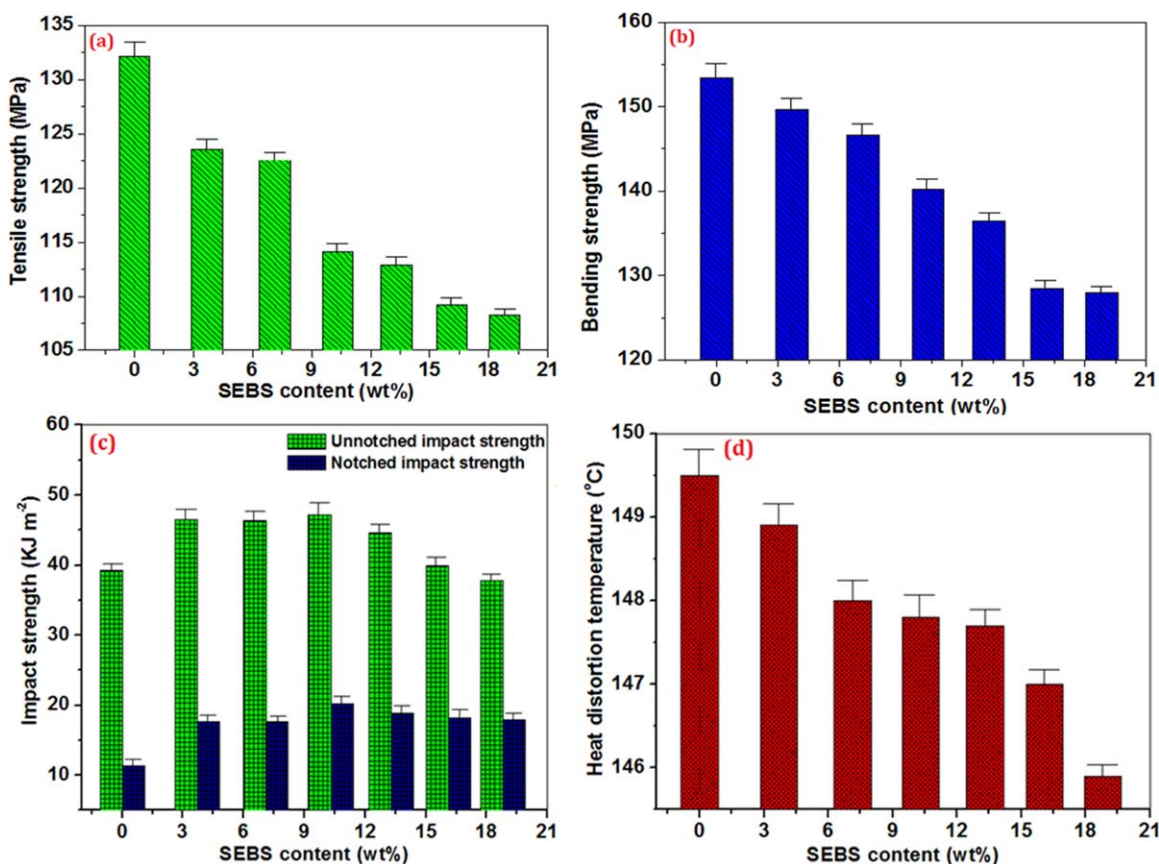


Figure 6. Effect of SEBS content on (a) the tensile strength, (b) the bending strength, (c) the impact strength, and (d) the heat distortion temperature of PPO/HIPS/GF (60/40/30) composites. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

is 60/40/30. The PPO/HIPS/GF 60/40/30 composites toughened by 3.7–10.3 wt % SEBS presented a good combination of mechanical and thermal properties. This study may provide guidance in developing simultaneously toughened and reinforced PPO/HIPS resin with SEBS and GF.

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