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Comparison of the toughening behavior of nylon 6 versus an amorphous polyamide using various maleated elastomers

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Abstract

The toughening effect of two types of elastomers based on ethylene/α-olefin copolymers, viz, an ethylene/propylene copolymer (EPR) with its maleated version, EPR-*g*-MA, and an ethylene/1-octene copolymer (EOR) with its maleated versions, EOR-*g*-MA-*X*% ($X=0.35$, 1.6, 2.5), for two classes of polyamides: semi-crystalline nylon 6 versus an amorphous polyamide (Zytel 330 from DuPont), designated as a-PA, was explored. The results are compared with those reported earlier based on a styrenic triblock copolymer having a hydrogenated midblock, SEBS, and its maleated version, SEBS-*g*-MA, elastomer system. Izod impact strength was examined as a function of rubber content, rubber particle size and temperature. All three factors influence the impact behavior considerably for the two polyamide matrices. The a-PA is found to require a somewhat lower content of rubber for toughening than nylon 6. Very similar optimum ranges of rubber particle sizes were observed for ternary blends of EOR-*g*-MA/EOR with each of the two polyamides while blends based on mixtures of EPR-*g*-MA/EPR and SEBS-*g*-MA/SEBS (where the total rubber content is 20% by weight) show only an upper limit for a-PA but an optimum range of particle sizes for nylon 6 for effective toughening. Higher EPR-*g*-MA contents lead to lower ductile–brittle transition temperatures (T_{db}) as expected; however, a-PA binary blends with EPR-*g*-MA have a much lower T_{db} than do nylon 6 blends when the content of the maleated elastomer is not high. A minimum in plots of ductile–brittle transition temperature versus particle size appears for ternary blends of each of the matrices with EOR-*g*-MA/EOR; blends based on SEBS-*g*-MA/SEBS, in most cases, show higher ductile–brittle transition temperatures, regardless of the matrix. However, blends with EPR-*g*-MA/EPR show comparable T_{db} with those based on EOR-*g*-MA/EOR for the amorphous polyamide but show the lowest ductile–brittle transition temperatures for nylon 6 within the range of particle sizes examined. For the blends with a bimodal size distribution, the global weight average rubber particle size is inappropriate for correlating the Izod impact strength and ductile–brittle transition temperature. In general, trends for this amorphous polyamide are rather similar to those of semi-crystalline nylon 6.

Keywords: Amorphous polyamide; Impact strength; Toughening

1. Introduction

Numerous studies have been reported on the rubber toughening of semi-crystalline polyamides like nylon 6 and nylon 66 using maleated elastomers [1–21]. By contrast, there are relatively few reports on rubber toughening of amorphous polyamides [22–24]. We recently initiated such studies primarily motivated by our interest in obtaining a better understanding of the toughening mechanisms of semi-crystalline polyamides by comparing the toughening responses of an amorphous matrix using the same elastomers [24]. In an earlier paper [25], we described the elastomer particle morphology for ternary blends of maleated and non-maleated ethylene-based elastomers with nylon 6 and an amorphous polyamide, Zytel 330 from DuPont. The elastomers used include an ethylene/propylene copolymer (EPR) with its maleic anhydride (MA) grafted version EPR-*g*-MA, and an ethylene/1-octene copolymer (EOR) with its maleated versions, EOR-*g*-MA-*X*% where *X* is 0.35, 1.6 and 2.5. Specifically, we have demonstrated when using mixtures of elastomers with different levels of maleation for achieving fine control of rubber particle sizes that elastomer phase miscibility becomes a significant factor in the morphology formed in addition to factors like the ratio of the two elastomers, the matrix type, the order of mixing and the mixing intensity (the extruder type), etc. In some cases, bimodal distributions of particle sizes were observed [25]. Obviously, the morphology of the resulting polyamide blend is a major factor in determining the final mechanical properties including Izod impact strength. The purpose of this paper is to report in some detail the toughening response of these two

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classes of polyamide matrices using these two types of elastomers. The effect of rubber content and particle size on Izod impact strength and the ductile–brittle transition temperature will be presented. A final paper [26] will explore the fracture behavior of selected blends in more detailed ways.

2. Experimental section

Table 1 shows the physical and mechanical properties of the materials employed in this study. The procedures for melt blending and morphology determination have been fully described elsewhere [25].

Standard tensile and Izod impact specimens, 0.318 cm thick, were formed using an Arburg Allrounder injection molding machine from blends containing 20 wt% rubber phase and 80 wt% polyamide matrix. The samples were tested ‘dry as molded’ using standard tensile (ASTM D638) and Izod (ASTM D256) procedures. Tensile testing was performed using an Instron model 1137. Modulus and yield stress were determined at a crosshead rate of 0.51 cm/min while elongation at break data were collected at 5.1 cm/min. Izod impact testing was done using a TMI Impact Tester (model 43-02) equipped with a thermal chamber so that the samples could be tested at a variety of temperatures. The testing procedures are given elsewhere [16]. The tested samples failed in three modes: a hinged break when tested above the ductile–brittle transition temperature, a complete break into two pieces when tested below the ductile–brittle transition temperature and a mixed mode in the ductile–brittle transition region where specimens of the same composition showed either a hinged or a complete break.

The dynamic mechanical properties of injection molded (3.18 mm thick) specimens of neat a-PA and nylon 6 materials and the neat elastomers employed in this work were determined by a Rheometric Scientific Dynamic Mechanical Thermal Analyser (DMTA) Mk III at a frequency of 1 Hz, a strain level setting of 4 which corresponds to about 0.07% strain, and under a single cantilever mode. All samples were cooled with liquid nitrogen to −100 °C and heated at a rate of 2 °C/min. The DMTA was calibrated prior to all testing.

3. Room temperature mechanical properties

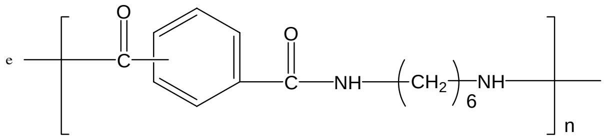
3.1. Tensile properties

Table 2 summarizes the mechanical properties of binary blends of each of the two polyamides with EPR-*g*-MA. As can be seen, modulus and yield stress are steadily reduced by the addition of EPR-*g*-MA. The elongation at break is rather erratic owing to a variety of issues that have been discussed in previous papers on similar blends [7,24]. Table 3 shows the mechanical properties of ternary blends of a-PA containing a total of 20 wt% rubber comprised of mixtures of EPR-*g*-MA

Table 1
Materials used

Designation used here	Materials (commercial designation)	Compositions	T_g (°C)[a]	Elastic modulus (MPa)[b]	MFR (g/10 min)[c]	Brabender torque (N m)[d]	Supplier
a-PA	Zytel 330[e]		127	1597		10.7	DuPont
Nylon 6[f]	B73WP[g]		55	1804		6.37[h]	Honeywell
EOR	Exact 8201	28 wt% octene	−34	24.1	~22	9.5	ExxonMobil
EOR-*g*-MA-0.35%	Exxelor VA 1840	28 wt% octene 0.35 wt% MA	−31	25.3	~25	9.2	ExxonMobil
EOR-*g*-MA-1.6%	Exxelor MDEX 101-2	28 wt% octene 1.6 wt% MA	−28	29.3	19	6.9	ExxonMobil
EOR-*g*-MA-2.5%	Exxelor MDEX 101-3	28 wt% octene 2.5 wt% MA	−28	29.7	20	6.3	ExxonMobil
EPR	Vistalon 457	53 wt% propylene	~−47	N/A		14.2[h]	ExxonMobil
EPR-*g*-MA	Exxelor 1803	53 wt% propylene 1.14 wt% MA	−47	3.2		9.76[h]	ExxonMobil
SEBS	Kraton G 1652	29 wt% styrene	~−36	40		8.58	Kraton Polymers
SEBS-*g*-MA	Kraton G 1901X	29 wt% styrene 1. 84 wt% MA	−36	66		6.37	Kraton polymers

[a] Data measured from the tan δ peak of DMTA.
[b] Data measured by the DMTA at 1 Hz and 25 °C.
[c] Data at 230 °C and 10 kg and provided by the supplier.
[d] Measured after 10 min at 240 °C and 60 rpm.
[e]



[f] Referred to as MMW nylon 6 in Ref. [24].
[g] Formerly Capron 8207F.
[h] Data from Ref. [15].