PROCESSING AND CHARACTERIZATION OF RECYCLED PC/ABS BLENDS WITH HIGH RECYCLE CONTENT

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Abstract

In order to develop a polycarbonate (PC)/ acrylonitrile-butadiene-styrene (ABS) product with a high content of recycled PC, a low molecular weight virgin PC was added to recycled PC to minimize batch-to-batch property variations in the compounded product. Six PC/ABS blends were prepared on a twin screw extruder by mixing 50 wt% virgin ABS and 0-25 wt% low molecular weight virgin PC with 25-50 wt% high purity recycled PC recovered from end-of-life electronics. These blends were characterized rheologically and mechanically. Results showed that this strategy could yield consistent quality resin blends with a high recycle content.

Introduction

Over the past decade there has been increasing public demand for plastics recycling due to the fact that the disposal of plastics has become a serious concern to the environment (1). However, in most cases recycling of polymers, which are recovered from used plastics products, is technically difficult and expensive. Post-consumer plastics are commingled. Mixed plastics have poor mechanical properties and thus have little value. Separating the chemically different plastics from each other, however, is expensive. In addition, there are batch-to-batch variations in properties of recycled polymers because of variability in the source and the composition of a given stream.

Therefore, solutions to the following questions have to be sought in order to ensure a plastics recycling process with success. i) Plastics separation by chemical type is essential, but what purity level is needed? ii) Contaminants and high molecular weight impurities are naturally present in polymers separated from mixed plastics. How do they affect the mechanical properties of the material? How can we upgrade these physical properties? iii) Recycled polymer varies from batch to batch in molecular weight and molecular weight distribution, and thus in thermal, flow, and mechanical properties. How can we minimize these variations in order to yield consistently high quality compounds?

These technical issues have been explored and investigated systematically during our work related to the developing of high-value applications for plastics separated from shredded residues of end-of-life computers, printers, and monitors. About 150 million lbs per year of polymers are used for the manufacturing of computer and electronics housings, and more than 50% of the total are PC, ABS, and PC/ABS blends. Those products are discarded after being used for only a few years. Since these are relatively expensive engineering polymers, recycling these polymers after their end-of-life is expected to be not only environmentally important and but also economically viable (2).

Funded by the US Department of Energy, we began to develop value-added materials from recycled PC and ABS recovered from electronics housings in 1999. Used electronics housings were collected from different sources, and the polymers were separated by chemical type by MBA Polymers of Richmond, CA. The short-term goal of our research is to reuse these polymers in their original, high-value applications by formulating a compounded resin by blending with virgin polymers. The long-term goal is to produce an acceptable, high quality, low cost, green product using as high a recycle content as possible.

The general research approach we have used has been i) to characterize recycled PC and ABS for their thermal, rheological, and mechanical properties; and ii) to develop compounding processes utilizing a high recycle content and upgrading the performance of the resulting blends. More specifically, the following strategies for materials development were or are being investigated: i) blending recycled polymers with chemically identical virgin resins, ii) blending recycled polymers with chemically different virgin resins, iii) adding glass fiber to reinforce recycled polymer blends, iv) adding elastomers to enhance the toughness of recycled polymer blends, v) using molecular weight modifiers to adjust the average molecular weight distribution, and vi) utilizing an on-line rheometer in the compounding process to tailor the rheology of the blends to yield consistent quality blends.

Our earlier studies (3) showed that 99% purity level is needed in order to retain key mechanical properties for recycling these polymers back into their original, high-value applications; and the properties of recycled polymers depend not only on the amount of impurity present but also on the chemical nature of impurities and contaminants. The latter even plays a greater part in relation to compatibility and thermal properties of polymers. At a given purity level, the mechanical properties of recycled material: i) will be negatively affected if the impurity is not compatible or processable at the extrusion temperature; and ii) will not be significantly affected if the impurity is both compatible and processable at the extrusion temperature.

Experimental results (4) also concluded that reuse of these recycled polymers in their original, high-value applications is possible by blending with chemically identical virgin resins and up to 15 wt% recycled polymer can safely be added to the virgin polymer without significantly altering processing and mechanical properties of the virgin resin when purity level is 99%. This '15% blending rule' is valid for both recycled PC/virgin PC and recycled ABS/virgin ABS. It practically means that adding 85% virgin resin to 15% chemically similar, recycled polymer is able to mask the batch-to-batch property variations of the used recycled polymers.

This paper reports our work on PC/ABS blends with the goal of increasing recycle content to a higher amount by blending recycled polymers with chemically different virgin resins. Considering PC with a higher market value than ABS, recycled PC is used to blend with virgin ABS. At first, virgin PC / virgin ABS blends were prepared and characterized in order to determine a particular composition at which recycled PC would be introduced. Then, a low molecular weight virgin PC was added to recycled PC at various ratios and the mixture was further blended with virgin ABS at the selected composition.

Experimental

Granulated, recycled PC (R-PC) was recovered from monitor housings and supplied at a purity level >99% by MBA Polymers of Richmond, CA. Virgin resins used included a general purpose grade PC (V-PC), Lexan 101, a low molecular weight PC, grade HF 1110 (HF-PC), and Cycolac GPM 5500 ABS (V-ABS), all manufactured by GE Plastics. The melt flow index data for these polymers were measured at 250C/1.2 kg on a Dynisco machine model LMI D4002 and are listed in Table 1.

The compositions of PC/ABS blends studied are listed in Table 1. All the blends were prepared using a Brabender twin screw extruder at a screw speed of 25 rpm and with an optimized extruder temperature profile for each composition (PC/ABS ratio). Extrudate strands were pelletized and the pellets were compression molded into specimens of different dimensions for testing. Rheological measurements were carried out on a Rheometric Scientific RMS800 with parallel plate fixtures of diameter 25mm with a gap of 1mm at 225C. A TA Instruments DSC 910 was used to measure Tg. Tensile tests were conducted on an Instron machine model 8501. Izod impact tests were conducted on a Satec BLI impact machine. More detailed descriptions on blend preparation and each type of test are available in previous papers (3,4).

Virgin PC/ ABS Blends

Rheological and Processing Behavior

Steady shear viscosity as a function of shear rate is shown in Figure 1 for virgin PC/ABS blends with different ABS contents. Adding 15% ABS into PC reduced the viscosity dramatically. Both 15% and 50% samples had lower viscosity than pure ABS, while 30% and 85% samples had slightly higher viscosity than 70% sample and pure ABS, but far lower than that of pure PC. According to these results, i) ‘15% blending rule’ doesn’t work for PC/ABS system; ii) the viscosity vs. composition trend presents negative deviation from the rule of mixtures; iii) PC/ABS blends behave more like pure ABS and enhancement of shear thinning behavior by blending PC with ABS improves the processability of PC.

Viscoelastic responses of PC/ABS blends are also complicated as represented in Figure 2 showing the effect of ABS content on storage modulus vs. frequency curves. 15% sample has the lowest storage modulus. 30% and higher compositions have a similar trend as pure ABS, i.e. showing a modulus plateau at low frequencies. The plateau height increases as the ABS content increases. But 70% and 85% samples have a higher elastic modulus than pure ABS, indicating an elasticity enhancement effect, that is, 70% and 85% blends are capable of storing more energy than pure ABS.

Plotting viscosity data at selected deformation rates as a function of ABS content yields Figure 3. Steady shear and dynamic data behave similarly but reveal the complexity of PC/ABS blends: the viscosity varies with composition in a wavelike manner, and there are a series of maxima and minima. But this complexity is reduced at higher shear rates; even at a shear rate of 1 1/s, the viscosity becomes weakly dependent on the ABS content in the range from 15% to 85%. From a practical viewpoint, this observation suggests a wide operating window of varying PC/ABS ratio to have processing behavior similar to pure ABS.

Mechanical Properties

Tensile properties and Izod impact strength of the blends are listed in Table 1 and graphically shown in Figure 4 as a function of ABS content. The tensile strength properties nearly follow the rule of mixtures but not the ductility and impact strength. PC/ABS blends have a much smaller elongation-at-break and impact strength than pure PC. With increasing ABS content, unlike Figure 3 where there are two maxima (at 30% and 85%), Figure 4 shows only one maximum at 30%.

Negative deviations in viscosity or Izod impact from the rule of mixtures for PC/ABS blends have also been observed by others (5-9). But series of maxima and minima as shown in Figure 3 have not been reported before. We ascribe these unusual blending effects to the multiphase characteristics of PC/ABS blends. ABS is a heterogeneous two phase terpolymer consisting of styrene-acrylonitrile (SAN) grafted polybutadiene dispersed in SAN. Addition of homogeneous, single phase PC into ABS changes the ratio of plastic phase component and rubber phase component and also alters the interaction between these two phases during processing, thus yielding PC/ABS blends of different morphologies and properties.

Virgin HF-PC/ Recycled PC/ ABS Blends

Rheological and Processing Behavior

Our focus is to reuse recycled PC in place of virgin PC to produce PC/ABS blends of high recycle content. From the study of virgin PC/ABS system, the PC/ABS (50:50) blend was chosen as our target compound due to its lower viscosity, good processing behavior, balanced mechanical properties, and its potential to reuse relatively high content of recycled PC. A low molecular weight (MW) virgin PC was used to modify the MW distribution of recycled PC because recycled PC was found to have higher MW than virgin PC used in this work (see MFI data in Table 1 and our papers (3,4)).

Effect of HF-PC content on steady shear viscosity of recycled PC/ABS blends is shown in Figure 5. The data for virgin PC/ABS (50:50) blend are also plotted for reference. Surprisingly, the results show that the replacement of virgin PC by higher MW recycled PC makes the viscosity of the blend decrease remarkably, rather than increase. This might be due to poor interfacial interaction (5). Adding 5% HF-PC further reduced the viscosity of the blend significantly. However, the blend with 10% HF-PC had a higher viscosity than the recycled PC/ABS blend without any HF-PC, but still much lower than that of virgin PC/ABS. As the HF-PC content further increases, the viscosity remains nearly unchanged. Note that recycled PC/ABS blends had stronger shear thinning than virgin PC/ABS. Similar observations can be drawn from storage modulus data in Figure 6. These trends are better represented in Figure 7 where the steady shear and dynamic viscosity data at selected deformation rates are plotted as a function of HF-PC content.

Mechanical Properties

Mechanical properties of recycled PC/ABS blends are also listed in Table 1. The tensile yield strength and Izod impact strength data are plotted as a function of HF-PC content in Figure 8. Significant reductions occur in mechanical properties after replacing virgin PC by recycled PC. The addition of 5% HF-PC into 45% recycled PC blended with 50% virgin ABS makes the material even more brittle. Adding 10% HF-PC recovers the mechanical properties to some extent, but with adding more HF-PC the properties remains nearly the same as those of 10% HF-PC blend. In Figures 7 and 8, both rheological and mechanical properties varied in a similar manner with composition.

Discussions and Conclusions

PC/ABS is a material commercially available for injection molding of computer and equipment housings. Blending PC with ABS improves the processability of PC by reducing the melt viscosity and enhancing shear-thinning behavior and also increases the heat distortion temperature of ABS material. Here compounding PC with ABS was developed as a strategy to produce a compound accommodating a high content of recycled PC.

With increasing ABS content, PC/ ABS blends present complex relationships between their compositions and rheology /mechanical properties. The complexity is due to inherent multiphase characteristics. There are a variety of morphological forms (dispersed, continuous, or co-continuous) in which the rubber (SAN-grafted polybutadiene) and the plastics (SAN and added PC) may take, depending on the composition, processing conditions, compatibility, and multiphase interactions (5-9). However, this complexity can be very much reduced by fixing ABS (rubber) content and varying PC type. As shown in Figures 7 and 8, for virgin PC/recycled PC /50% ABS blends, there was a parallel relationship between rheological /processing properties versus composition and mechanical properties versus composition. All properties follow similar trends varying with composition. This feature is of significance with respect to processing and will make it possible to control the properties of compounds with the use of an online rheometer.

Finally, this study has demonstrated that a PC/ABS blend comprising 40 wt% recycled PC, 10 wt% low molecular weight virgin PC and 50 wt% virgin ABS would be an acceptable product having a high recycle content and balanced processing and mechanical properties.

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Table 1. The Compositions and Mechanical Properties of PC/ABS Blends (a: g/10min)

Code	High Flow PC MFI=4.56[a]	Recycled PC MFI=0.622[a]	Virgin PC MFI=1.32[a]	Virgin ABS MFI=2.97[a]	Tensile Yield Strength MPa	Elongation-at-Break %	Izod Impact Strength J/m
V-PC/V-ABS			100%	0%	59.83	37.1	1268
			85%	15%	56.73	9.13	271.2
			70%	30%	55.79	14.4	437.6
			50%	50%	51.78	11.7	253.0
			30%	70%	46.05	8.22	166.1
			15%	85%	45.71	5.59	135.0
			0%	100%	42.80	7.12	213.4
HF-PC/R-PC /V-ABS	0%	50%		50%	38.09	3.18	43.61
	5%	45%		50%	25.88	1.97	33.02
	10%	40%		50%	45.35	4.77	72.92
	15%	35%		50%	42.84	4.25	64.01
	20%	30%		50%	44.58	5.86	72.79
	25%	25%		50%	43.39	4.20	73.72

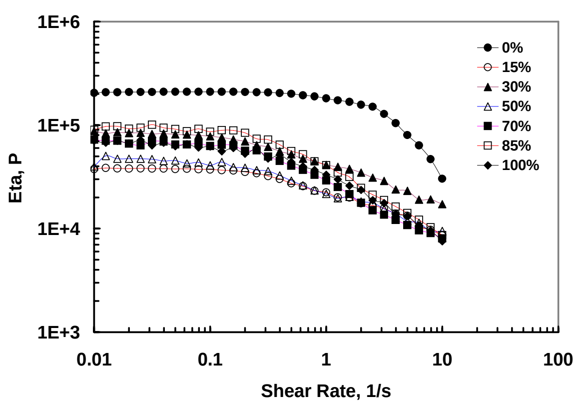

Figure 1. Effect of V-ABS wt% on steady shear viscosity versus shear rate for virgin PC/ virgin ABS blends (225C).

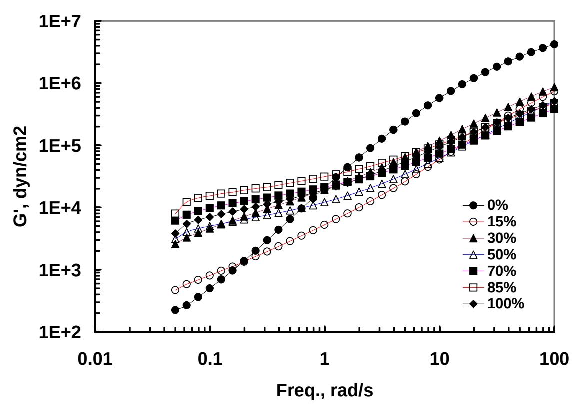

Figure 2. Effect of V-ABS wt% on storage modulus versus frequency data for virgin PC/ virgin ABS blends (225C, strain 10%).

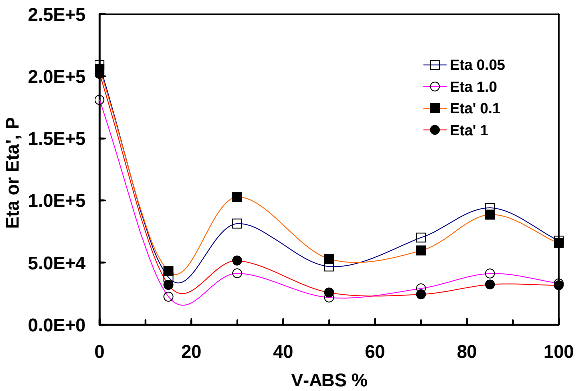

Figure 3. Steady shear viscosity or dynamic viscosity at selected deformation rates versus V-ABS wt% for virgin PC/ virgin ABS blends.

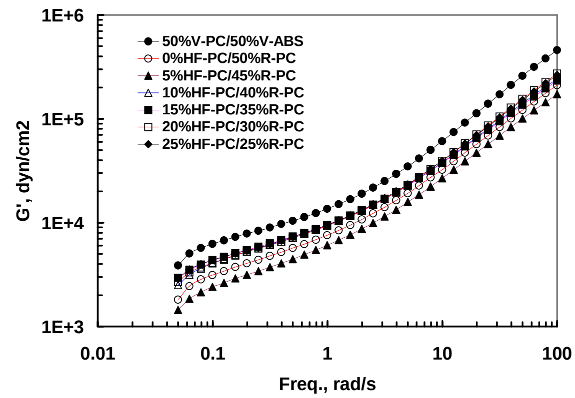

Figure 6. Effect of PC type and HF-PC wt% on storage modulus versus frequency for virgin HF-PC/ recycled R-PC/ virgin V-ABS blends (225C, strain 10%).

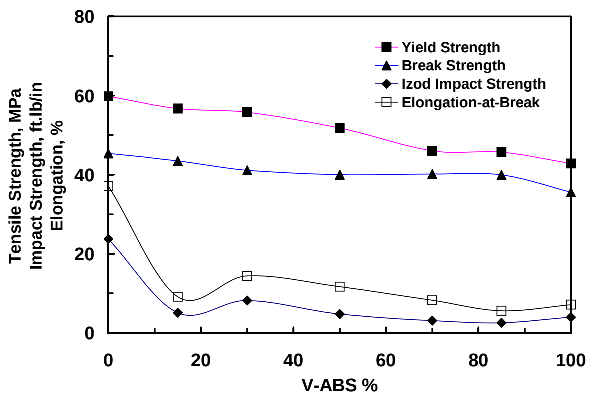

Figure 4. Mechanical properties versus V-ABS wt% for virgin PC/ virgin ABS blends.

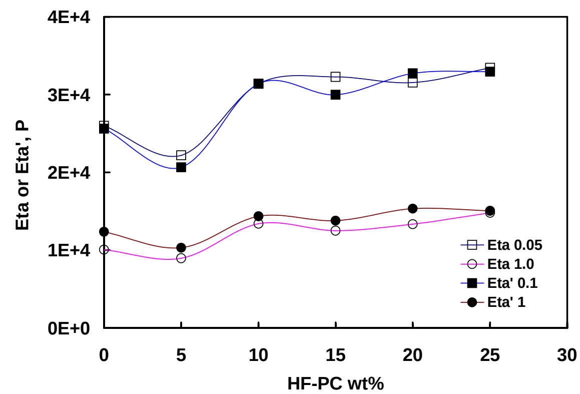

Figure 7. Steady shear viscosity or dynamic viscosity at selected deformation rates versus HF-PC wt% for virgin HF-PC/ recycled R-PC/ virgin V-ABS blends.

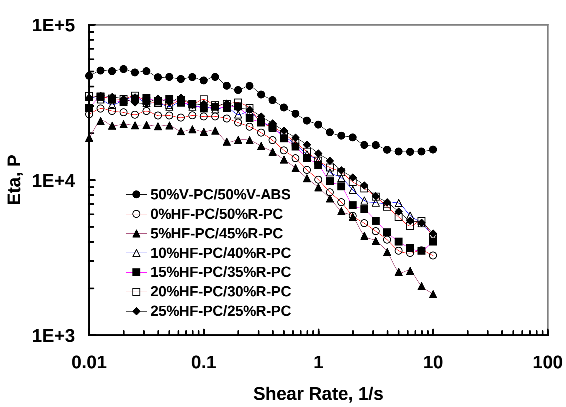

Figure 5. Effect of PC type and HF-PC wt% on steady shear viscosity versus shear rate for virgin HF-PC/ recycled R-PC/ virgin V-ABS blends (225C).

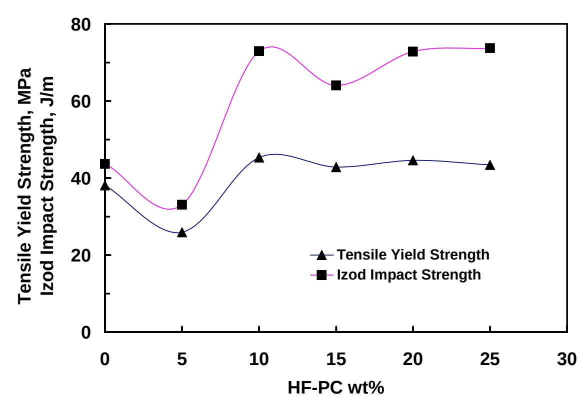

Figure 8. Mechanical properties versus HF-PC wt% for virgin HF-PC/ recycled R-PC/ virgin V-ABS blends.

Keywords: Recycled polycarbonate, PC/ABS blends, mechanical properties, end-of-life electronics