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Fly ash reinforced thermoplastic vulcanizates obtained from waste tire powder

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ABSTRACT

Novel thermoplastic composites made from two major industrial and consumer wastes, fly ash and waste tire powder, have been developed. The effect of increasing fly ash loadings on performance characteristics such as tensile strength, thermal, dynamic mechanical and magnetic properties has been investigated. The morphology of the blends shows that fly ash particles have more affinity and adhesion towards the rubbery phase when compared to the plastic phase. The fracture surface of the composites shows extensive debonding of fly ash particles. Thermal analysis of the composites shows a progressive increase in activation energy with increase in fly ash loadings. Additionally, morphological studies of the ash residue after 90% thermal degradation shows extensive changes occurring in both the polymer and filler phases. The processing ability of the thermoplastics has been carried out in a Monsanto processability testing machine as a function of shear rate and temperature. Shear thinning behavior, typical of particulate polymer systems, has been observed irrespective of the testing temperatures. Magnetic properties and percolation behavior of the composites have also been evaluated.

1. Introduction

The main problem associated with recycling of waste rubber tire powder is the degradation undergone by the elastomeric components during its lifetime. Consequently, new strategies have to be developed to obtain value-added polymers with good mechanical and processing characteristics. Blending recycled rubber with other polymeric materials has been an attractive alternative to disposal of the rubber. Toughening of brittle plastics by incorporation of a small amount of waste ground rubber tire (WGRT) is a widely used commercial process. The rubber forms discrete particles with a diameter of about 1 μm or less. These particles act as stress concentrators initiating crazing, but the chief drawback of the rubber particles has been the difficulties in obtaining adequate properties from the resultant blends. Efforts to develop recycled rubber/plastic blends have logically followed earlier blending research that produced both thermoplastic elastomers and rubber-toughened plastics (Coran, 1987). Results of these numerous studies on virgin materials have provided criteria for a successful blend. For efficient mixing of the constituting polymers, the two components must be thermodynamically incompatible enough to phase separate, but not so dissimilar that intimate intermixing cannot be accomplished (Ho et al., 1990; Jang et al., 1984).

Of the commercially available thermoplastic elastomers, some are expensive, special-purpose materials. The olefin types, which include blends of natural rubber with crystalline polyolefins, and those of ethylene propylene terpolymer (EPDM) with polyolefins are cheaper, and similar in price to the styrene–butadiene–styrene (SBS) block copolymer types of thermoplastic rubbers. The olefinic types have potential uses in flexible automotive components such as bumpers, spoilers requiring materials in the range 90 shore A–60 shore D (Montoya et al., 2004).

Elastomer composites are reinforced by the addition of filler materials to improve the mechanical, electrical, thermal, optical, and processing properties, while reducing their cost. Of more than 100 different types of organic and inorganic reinforcing materials researched and reported in the literature, only a few fillers like carbon black and silica have been commercialized and used extensively.

Fly ash is a waste product produced in huge quantities by coal-based thermal power plants. The current annual world production of fly ash from thermal power plants and metallurgical industries is about 650 million metric tons, of which only about 7% is being used by the cement and concrete industries; the remainder is being disposed in landfills. This paper is a part of our efforts to produce value-added products based on post-consumer waste materials like waste tire rubber.

We recently reported the development of novel thermoplastics from waste rubber tire powders and polypropylene by dynamic reaction inside co-rotating twin screw extruder (Lee et al., 2007). This manuscript is continuation of that work and reports the utility

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of fly ash as reinforcing filler in these thermoplastics. The effect of increasing fly ash loadings on morphology, tensile, thermal, and dynamic mechanical properties has been investigated.

2. Experimental

2.1. Materials

The basic materials used in the study and their sources are as follows: the WGRT was ground by wet grinding method and was supplied by Hongbok Industry, Korea. The composition of the waste tire rubber is: polymer content of 48.5% with natural rubber (NR) and styrene-co-butadiene rubber (SBR) in a 1:4 ratio. The other components of waste rubber are organic additives (13.4%), carbon black (27.7%) and ash (10.4%). Other basic materials used in this study and their sources are as follows. Isotactic PP 1088 was purchased from Korea petrochemical, Korea. The triblock copolymers, SEBS-g-MA (maleated styrene–ethylene/butylene–styrene), were supplied by Shell Chemical Co. Ltd., USA. This copolymer has styrene end blocks and a hydrogenated butadiene mid block reassembling an ethylene/butylene copolymer. SEBS-g-MA (Kraton FG1901X) is SEBS functionalized with 1.84 wt% maleic anhydride onto the hydrocarbon chains of the mid block. The typical composition of the TPV had 65 phr (parts per hundred rubber) of GRT, 35 phr of PP, 10 phr of SEBS-g-MA[6] with Dicumyl peroxide (DCP) of purity >98% used as cross-linking agent. Class F fly ash obtained from burning of bituminous coal was obtained from the thermal power plant of Korea South East Power Co. Ltd., Sacheon, Korea. Prior to addition in the composite, fly ash was sieved through a 20-μm mesh.

2.2. Characterization and testing

2.2.1. Physico-mechanical properties

The mechanical properties, comprising tensile strength and elongation at break, were measured using a Tensilon 2000, Universal testing machine, according to ASTM D 638. The cross-head speed was 50 mm min^{-1}.

2.2.2. Scanning electron microscopy

SEM microphotographs have been obtained using a field emission scanning electron microscope using a Philips XL30 S FEG (Netherlands) at an operating voltage of 15 kV after auto sputter coating of the sample surface with gold.

2.2.3. Thermogravimetric analysis

TGA scans from room temperature to 700 °C were obtained on a Perkin–Elmer 7 Series thermal analysis system at a scan rate of 20 °C/min in a nitrogen atmosphere.

2.2.4. Magnetic properties

Magnetic hysteresis loops were recorded on a vibrating sample magnetometer, Princeton Measurements Corporation (PMC), 3900-02, from −10,000 to +10,000 Gauss at room temperature.

2.2.5. Extensional rheology

The processability of the composites has been studied using a Merwin RH2200-capillary type rheometer as a function of composition of fly ash and temperature over a wide range of shear rates.

2.2.6. Dynamic mechanical properties

The dynamic mechanical spectra of the samples were obtained by using a Seiko Exstar 6000 (DMA/SS6100, SEICO INST, Japan). The samples specimens were analyzed in tensile mode at a constant frequency of 1 Hz, and a temperature range from 25 to 180 °C at a heating rate of 2 °C/min.

3. Results and discussion

3.1. Analysis of fly ash

Representative SEM microphotograph and chemical composition of fly ash are shown in Fig. 1a and b, respectively. From the SEM pictures, it can be observed that constituents of fly ash comprise a variety of shapes of which spherical particles in micrometer scale are dominant. The chemical composition of fly ash is shown in Table 1 on a weight and an atomic basis; the fly ash contains oxides of inorganic elements such as sodium, aluminum, silica, potassium, calcium and iron. The presence of unburnt carbon can also be observed.

3.2. Mechanical properties

Fig. 2 shows the variation of tensile strength with filler concentration of fly ash. It is observed that the tensile strength decreases with increase in the filler concentration of fly ash. A SEM microphotograph of the fracture surface is shown in Fig. 3. Irrespective of the filler loadings, extensive debonding between the fly ash and polymer matrix phase is observed. A continuous decrease in elongation at break with increasing fly ash concentrations can also be observed in Fig. 2. Increasing concentrations of filler leads to increasing interference (Sombatsompop et al., 2004) by the filler with the mobility or deformability of the matrix. This interference is created through physical interaction and immobilization of the polymer matrix by imposing mechanical restraints. In our multiphase composite system of rubber/plastic (WGRT/PP), composites

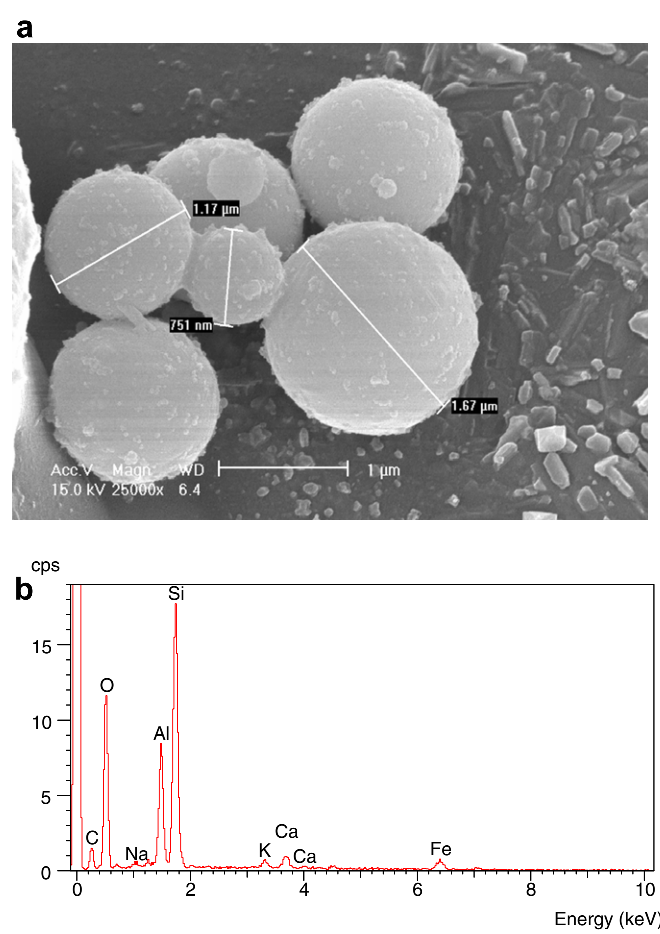

Fig. 1. SEM micrograph and EDS spectra of fly ash.