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Short Communication

Study of microcellular injection-molded polypropylene/waste ground rubber tire powder blend

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ABSTRACT

Microcellular polypropylene/waste ground rubber tire powder blend processing was performed on an injection-molding machine with a chemical foaming agent. The molded samples produced based on the design of experiments (DOE) matrices were subjected to tensile testing and scanning electron microscope (SEM) analyses. Molding conditions and waste ground rubber tire (WGRT) powder have been found to have profound effects on the cell structures and mechanical properties of polypropylene (PP) and waste ground rubber tire powder composite samples. The result shows that microcellular PP/WGRT blend samples exhibit smaller cell size and higher cell density compare with polypropylene resin. Among the molding parameters studied, chemical foaming agent weight percentage has the most significant effect on cell size, cell density, and tensile strength. The results also suggest that tensile strength of microcellular PP/WGRT composites is sensitive to weight reduction, and skin thickness.

1. Introduction

Motivation of the plastic industry towards the introduction of a large number of gas bubbles inside a polymer was to reduce the amount of polymer needed and to increase the mechanical resistance (impact) and/or insulation properties for specific applications like packaging and low stress structural materials [1,2]. Another way to drive down costs is to use recycled materials. The usage of waste ground rubber tire (WGRT) powder as dispersed elastomeric phase in polypropylene (PP) matrix offers an interesting opportunity for recycling of waste rubber. Many research works, including our own, has been done on utilization of rubber waste by incorporating waste rubber power into thermoplastics to obtain impact-modified thermoplastics [3–5] and the thermoplastic elastomers (TPEs) [6–10]. So from standpoint of cost and environmental requirements, the PP/WGRT composites foaming technology is fulfill the requirement of lower cost, lighter weight and better fuel economy, therefore, it is worthwhile to study the processability of PP/WRT blends for foaming applications. Foamed polymers can be produced by utilizing either a chemical or a physical blowing agent. Azodicarbonamide and modified azodicarbonamide compounds are the most popular chemical blowing agents (CBA) used [11] for this research.

There are many types of polymer foaming processes, such as foam extrusion, foam injection molding, compression molding, and microfoaming. The advantages of foam injection molding include the absence of sink marks on the part surface, reduced weight, low injection pressure, faster production cycle time, and high stiffness-to-weight ratio [12–16]. Due to these advantages, the structural foam injection molding technology has been widely used for manufacturing large products that require geometric accuracy.

The purpose of this work to present another attempt to obtain 'value added products' from PP/WGRT composites and deals with the production of injection-molded cellular foams from the same. In this paper, injection foam molding technology with a chemical blowing agent is applied to PP/WGRT blend, and the critical processing parameters, affecting cell morphology and physical properties of the blend foams, are investigated.

2. Experimental

2.1. Materials

Polypropylene (R520Y) was manufactured by SK Corporation, South Korea and maleic anhydride-grafted styrene–ethylene–butylene–styrene (SEBS-g-MA, Kraton FG-1901X) were obtained from Shell Chemical Co. Ltd., USA.

The chemical blowing agent used was azodicarbonamide (AZDC, decomposition temperature 195–202 °C), manufactured by Kumyang Corporation, Korea. Waste ground rubber tire powder (WGRT) was produced by wet grinding method and supplied by Hongbok Industry, Korea, which size was characterized to be 50 mesh as shown in Fig. 1.

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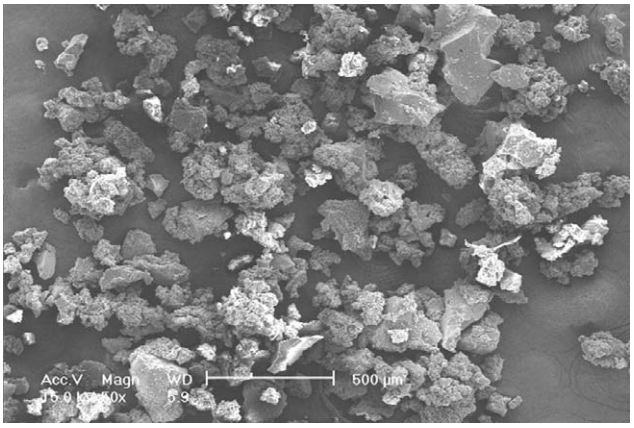

Fig. 1. SEM microphotograph of 50 mesh of waste ground rubber tire powder (scale bar is 500 μm).

2.2. Experimental design

The experiments were conducted using materials PP/WGRT blend based on the fractional factorial design of the Taguchi three-level L9 orthogonal arrays, as shown in Table 1 [15,16]. The L9 experiments contained four different molding parameters (blowing agent, shot size, injection pressure, injection speed) at three different levels. For the purpose of comparison with PP resin, the experiments were also made at Trials 7 and 9 for PP resin. For each trial in the L9 experiment, 72 specimens were collected.

2.3. Processing and foaming

The PP/WGRT (60/40) blend was performed by using a modular intermeshing twin screw extruder (BauTech, Republic of Korea, D = 19 mm, L/D = 40/19) in our lab. The screw speeds were kept at 100 rpm, the barrel temperature was maintained at 200, 210, 220, and 230 °C from the hopper to the die. A small quantity of SEBS-g-MA was added to the PP/WGRT blend as compatibilizer, which content is 10 wt.% based on the total weight of PP and WGRT. The compatibilizers act as a polymeric surfactant, lowering surface tension and promoting interfacial adhesion between different phases in a polymer blend. They can also influence in the reduction of the physical size of the domains, and stabilize the morphology of the blends. The extrudate was pelletized and dried under vacuum at 80 °C for 12 h to remove any residual water. The molding experiments were conducted using a reciprocating screw-type (WONIL, WL-HV-80) injection molding machine. Foamed samples were prepared by using the chemical blowing agent (AZDC) and an accelerator (ZnO) to ensure complete decomposition, and the ratio of AZDC:ZnO was fixed at 5:1.

Table 1
L9 fractional orthogonal experimental design with PP/WGRT microcellular blend.

Trial	CBA content (wt.%)		Shot size (mm)		Injection speed (%)		Melt temperature (°C)	
	Level	Setting	Level	Setting	Level	Setting	Level	Setting
1	1	0.4	1	47	1	70	1	185
2	1	0.4	2	48.5	2	80	2	195
3	1	0.4	3	50	3	90	3	205
4	2	0.6	1	47	2	80	3	205
5	2	0.6	2	48.5	3	90	1	185
6	2	0.6	3	50	1	70	2	195
7	3	0.8	1	47	3	90	2	195
8	3	0.8	2	48.5	1	70	3	205
9	3	0.8	3	50	2	80	1	185

2.3.1. Foam characterization

The tensile mechanical properties of foam sample were tested following the ASTM D638 on a Tensometer 2000 (Bong Shin) mechanical testing machine at room temperature. Foam samples used for tensile testing had a thickness ranging from 3 mm to 4 mm, depending on the expansion ratio of the sample under various foaming conditions. The displacement rate of the crosshead was 50 mm min^{-1}. Six samples from each molding trial were tested.

The foamed samples were fractured in liquid nitrogen, coated with an approximately 10 nm thick layer of gold on the fractured surface, and observed with a Philips XL 30S scanning electron microscope (SEM). The cell sizes, cell densities and relative densities were characterized. The cell diameter (D) is the average of all the cells on the SEM photo, usually more than 100 cells were measured by using the following equation [17]:

$$D = d/(\pi/4) \tag{1}$$

where d is the measured average diameter in the micrograph.

The density of foam and unfoamed samples was determined from the sample weight in air and water, respectively, according to ASTM D 792 method A. Then the density of the foamed sample is divided by the density of the unfoamed sample to obtain the relative density (ρ_r). The void fraction occupied by the microvoids (V_f) was calculated by following equation:

$$V_f = 1 - \frac{\rho_f}{\rho_m} \tag{2}$$

where ρ_m and ρ_f are the density of the unfoamed polymer and foamed polymer, respectively.

The cell density (N_0) based on the unfoamed sample was calculated as

$$N_f = \left(\frac{n}{A}\right)^{3/2} \tag{3}$$

$$N_0 = \frac{N_f}{1 - V_f} \tag{4}$$

where n is the number of bubbles in the micrograph of area A in cm^2, V_f is the void fraction occupied by the microvoids and N_f is the cell density based on the foamed sample [18].

2.4. Signals-to-noise ratio analyses

We used the S/N ratio to analyze the effect of the processing parameters on cell density, cell size and tensile strength. The S/N ratio enables the user to determine whether varying the levels of a certain parameter will result in significant changes in the response of interest. The goal of this study was to minimize the cell size and maximize the cell density of the microcellular injection-molded blend, we used the so-called "the smaller-the-better" and "larger-the-better" S/N ratio analyses, respectively [19]. For high cell density, the larger-the-better characteristics are looked for. The larger-the-better S/N formulation is expressed as:

$$S/N = -10 \times \log\left(\frac{1/y_1^2 + 1/y_2^2 + \cdots + 1/y_n^2}{n}\right) \tag{5}$$

where y is the experimental measurement of the cell density and n is the number of samples per trial. To calculate the S/N ratio, it is commonly accepted to employ the measured data directly as the logarithmic operands without normalization.

In order to investigate the influence of molding conditions on the cell size and tensile strength, the S/N ratio method was also employed. Since it is desirable to have finer microcells, the smaller-the-better S/N formulation was adopted for the cell size analysis and expressed as: