Composites: Part B 62 (2014) 230–235

Contents lists available at ScienceDirect

Composites: Part B

journal homepage: www.elsevier.com/locate/compositesb

Short carbon fiber reinforced polycarbonate composites: Effects of different sizing materials

Cem Ozkan [a], N. Gamze Karsli [b], Ayse Aytac [a,b,*], Veli Deniz [a,b]

[a] Department of Polymer Science and Technology, Kocaeli University, Turkey
[b] Department of Chemical Engineering, Kocaeli University, Engineering Faculty, 41380 Kocaeli, Turkey

ARTICLE INFO

Article history:
Received 30 July 2013
Received in revised form 27 February 2014
Accepted 5 March 2014
Available online 13 March 2014

Keywords:
A. Carbon fiber
A. Polymer–matrix composites (PMCs)
B. Mechanical properties

ABSTRACT

In this paper, effects of the sizing material type and level on the mechanical, electrical and morphological properties of the short carbon fiber (CF) reinforced polycarbonate (PC) composites were investigated. Unsized CF and the CFs which were sized with epoxy/phenoxy(EPO_PHE), polyimide(PI) and phenoxy(PHE) were used as reinforcement materials. Fiber length distribution analysis indicated that sizing protected the CFs breakage into the smaller lengths during the processing. Effects of the sizing material type and level on the mechanical properties of CF reinforced PC composites were investigated by means of tensile and izod impact strength tests. Tensile test results revealed that tensile strength and modulus values of sized CF reinforced PC composites were higher than that of unsized CF reinforced PC composites. Besides, effect of the sizing material level on the tensile properties of composites changed with respect to the sizing material type. It was also found that the measured effects of the sizing agent type and level on the notched izod impact strength of composites were not so significant. In addition to this, it was found that sized CF reinforced PC composites had higher electrical conductivity values than unsized CF reinforced PC composites. Also, PHE sized CF reinforced composites had the highest electrical conductivity value among the other composites. Better interactions between EPO_PHE and PHE sized CF and PC matrix were observed from the scanning electron microscope analysis. As a result of this study, PHE and EPO_PHE sized CFs can be suggested as proper reinforcements for PC matrix.

1. Introduction

Carbon fibers (CFs) have been widely used as reinforcement materials in composite manufacturing due to their exceptional properties such as high specific modulus, strength, stiffness, electrical properties and low density. While chemical and thermal properties of composites mainly depend on matrix materials, mechanical properties of composites such as strength depend on properties of carbon fiber and fiber/matrix interfacial adhesion strength. If there is good fiber/matrix adhesion strength, the applied load can be transferred from matrix to fiber more efficiently [1]. However, generally adhesion between carbon fiber and thermoplastic polymer matrix is poor because of the inert characteristics of fiber surface and matrix material [2,3]. Polycarbonate (PC) is one of these polymers and it is used in the short fiber reinforced advanced composites [4]. Different modification techniques have been applied to fiber surface to improve the interfacial adhesion between thermoplastic matrix and carbon fiber due to the lack of adhesion between them [1,2,4,5]. Plasma oxidation, radiation and chemical treatments are some of various methods which were applied to carbon fiber surface [6–13]. Another efficient method for fiber surface modification is sizing or coating of fiber surface with a thin polymeric layer. Sizing method prevents the fiber from the breakage during filament winding, prepreg, weaving and other composite manufacturing processes [7,8]. This method also improves the interfacial adhesion between fiber and matrix, since sizing material includes functional groups which can react with constituents of composite [2]. Besides, chemical structures of the sizing material and matrix should be similar due to the 'similar dissolve mutually theory' [6]. Consequently, different matrix materials require proper sizing materials and it is important to choose the ideal sizing material for polymer matrix material in order to obtain better composite properties.

To our knowledge, there has been no study in which the effects of the sizing agent type and/or level on the properties of carbon fiber reinforced polycarbonate composites were investigated together. But there are a few studies which are investigated the

* Corresponding author. Current address: Chemical Engineering Department, Kocaeli University, Engineering Faculty, 41380 Izmit, Kocaeli, Turkey. Tel.: +90 262 303 35 32.
E-mail address: aaytac@kocaeli.edu.tr (A. Aytac).

http://dx.doi.org/10.1016/j.compositesb.2014.03.002
1359-8368/

adhesion between CF and PC matrix. Danyadi et al. [4] studied the effects of four different coupling agents on the properties of CF reinforced PC composites. These coupling agents were containing epoxy, anhydride and isocyanate functional groups. They found that while the coupling agents which contain epoxy and isocyanate reacted with PC matrix, coupling agents which contain anhydride functional groups did not. Kushwaha et al. [14] studied the properties of polycarbonate composites which were reinforced with nickel coated carbon fiber. Their results showed that tensile, flexural properties and abrasion resistance of composites improved with the surface coating of fibers. Kim et al. [15] analyzed the effects of fiber length, fiber content, screw speed and fiber sizing on rheological and mechanical properties of polycarbonate/carbon fiber composites. They showed that the final fiber length of sized carbon fibers was greater than that of unsized carbon fibers after the extrusion process and they concluded that the final fiber length has a strong effect on the rheological and mechanical properties of composites. Raghavendran and Drzal [3] investigated the adhesion between PC matrix and CF on which two types of polymer was grafted to create covalent linkages. These polymers were low molecular weight PC and PMMA. They performed interfacial shear strength adhesion measurements and observed that the level of interfacial adhesion was improved by using polymer grafted carbon fiber in the composites. Their results showed that the improvement in interfacial adhesion was ranged from 20% to 80%, when polymer grafted carbon fibers were used in composites.

In addition to these studies, there are some studies in the literature which investigated the effects of sizing agent properties such as molecular weight and concentration. Zhang et al. [2,16] studied the influence of different molecular weight sizing agents on the properties of carbon fibers and their composites. Their study revealed that interfacial shear strength and hydrothermal ageing decreased in the case where high and low molecular weight sizing agent was used. On the other hand, interfacial shear strength and hydrothermal ageing improved when moderate molecular weight sizing agent was used. In another study [17], the effect of sizing agent concentration on the performance of CF reinforced epoxy based composites was investigated. In this study, three levels of sizing agent concentration were studied and it had been found that the optimum level of sizing agent was 1.5 wt.%.

In this study, it was aimed to investigate the effects of sizing material type and level on the properties of carbon fiber reinforced polycarbonate composites. For this purpose, unsized and CFs which were sized with three different types of sizing agent were used as the reinforcement material. Tensile test and izod impact test were carried out to investigate the effect of sizing material type and level on mechanical properties of carbon fiber reinforced PC composites. In addition to this, thermal stability of sizing materials was investigated by thermogravimetry analysis (TGA). Optical microscope analysis was performed to determine the fiber length distribution. Scanning electron microscope (SEM) was also used to analyze the fracture surfaces of composites.

2. Materials and methods

Polycarbonate (Wonderlite PC 110) was used as matrix material and supplied from Kempro (Istanbul). PAN-based carbon fibers (Aksaca), which were unsized and sized with three different materials, were supplied by Akkök Group (Turkey) and used as the reinforcement materials. Sizing materials were epoxy/phenoxy (EPO_PHE), phenoxy (PHE) and polyimide (PI). Level of sizing materials on CF surface were 1%, 2% and 3% by wt.%. Carbon fiber content in composites was kept constant at 30% by wt. and the initial fiber length was 6.0 mm. Composites were prepared by using a laboratory scale DSM Xplore micro-compounder at 295 °C processing temperature, 100 rpm screw speed and 3 min mixing time. After the extrusion process, all compounds were molded by using a laboratory scale injection molding machine (DSM Xplore 12 ml Micro-injection Molder) with 295 °C barrel temperature, 100 °C mold temperature; and 10 bars injection pressure.

Samples were burned in an ash oven for 30 min at 600 °C to investigate the fiber length distribution of composites. The residual ash was dispersed in water and then CFs were isolated from the composite. After that CFs were transferred to glass slides and images of fibers were obtained from optical microscope. These images were analyzed by using Image J® in order to determine the fiber length distribution.

Tensile properties were investigated according to ISO-527 by using Shimadzu 100 kN model universal testing machine. Dimension of the test samples were 10 mm width, 4 mm thickness and 106 mm length. Tensile strength at yield and strain at break values of composites were determined by using 5 mm/min crosshead speed. Notched izod impact strength test was performed according to ISO 180/1A by using a Ceast machine with a 5.5 J hammer and 3.46 m/s impact velocity. After these tests, average of five measurements was reported with standard deviations.

Thermogravimetric analysis (TGA) was conducted to determine the thermal stability of CFs which were unsized and 3 wt.% sized with different sizing materials at the processing temperature. Thermal analysis was performed by using a Perkin Elmer TGA Instrument. For isothermal TGA study, temperature was increased from 30 °C to 295 °C as quickly as possible and held at this temperature for 3 min under atmospheric conditions similar to conditions during composite preparation. Weight loss data at constant temperature were collected as a function of time by using special software.

Electrical resistivity values of composites were measured with 2-point-probe technique by using Haoyue M890G Digital Multi Meter. For a good electrical contact in two point probe technique, copper wires were attached to both ends of the test specimen with silver paste. Resistivity measurements were performed by contacting probes with these copper wires, after the hardening of silver paste. After obtaining the resistance values of each sample, electrical conductivity values of composites were calculated [18,19] and average results of five measurements were reported for each prepared composite:

$$\sigma(\mathrm{S/cm}) = \frac{\text{Sample Thickness (cm)}}{\text{Electrode Area (cm}^2) \times \text{Resistance } (\Omega)} \quad (1)$$

Tensile fractured surface morphology of composites was observed by using scanning electron microscope (SEM) (JEOL JSM-6510). All the sample surfaces were sputter coated with gold and palladium before the observation.

3. Results and discussion

3.1. Fiber length distribution

It is well known that, in the extrusion process, an excessive amount of shear stress is applied to composite during composite preparation and then composite is transferred to injection machine for molding. Meanwhile, fibers in the composite are broken and the fiber length distribution in the composite changes [20,21]. In this study, the effect of sizing material on the ultimate fiber length distribution in PC composites was investigated by using Image J® analyzing program. Ultimate fiber length distribution curves on number average basis for unsized and sized CF reinforced PC composites were given in Fig. 1. It can be seen from Fig. 1 that the measured ultimate fiber lengths are in the range from 25 to 500 μm. Results of the fiber length distribution analysis shows that while