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Effect of carbon black on improving thermal stability, flame retardancy and electrical conductivity of polypropylene/carbon fiber composites

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ABSTRACT

In this work, carbon black (CB) was introduced into polypropylene/carbon fiber (PP/CF) composite to fabricate multifunctional composites with the improved thermal stability, flame retardancy and electrical conductivity. The morphology investigation showed that one-dimensional CF and zero-dimensional were well dispersed in the PP matrix, and the multistage structure was formed in PP matrix. Compared to pristine PP, the maximum weight loss temperature under air atmosphere was enhanced by 79 °C. The peak value of the heat release rate measured by a cone calorimeter was significantly reduced by 70%, and the total heat release decreased from 198 to 166 MJ/m^2. The dramatically enhanced flame retardancy of PP composites was attributed to the formation of a strong three-dimensional (3D) network structure in PP matrix where one-dimensional CF acted as bridges connecting individual zero-dimensional CB, and the accelerated oxidation crosslinking reaction of PP radicals by CB and CF. Furthermore, the electrical conductivity of PP composites was significantly enhanced to 7.8 S/m due to the formation of 3D conductive pathways from CB and CF within the matrix.

1. Introduction

Polymer/carbon fiber (CF) composites have excellent mechanical and chemical properties, such as high specific strength and modulus, good anti-fatigue and corrosion resistance. They have become attractive alternatives to conventional metallic materials in many applications, such as ships, buildings, electrical and electronic components [1,2]. However, one of the shortcomings for most polymer/CF composites is flammable, and sometimes toxic gases will be released when they are subjected to radiant heat or fire [3]. Owing to their inherent flammability, fire safety and fire protection of polymer/CF composites are of great concern. Generally, the combustion takes place in at least three interdependent phases, namely condensed phase, gas phase and interphase [4]. The decomposition of polymers can be simply ascribed to the breakdown of polymer chains to form macromolecular free radicals and H· throughout the combustion progress [5]. There are several methods to improve fire retardancy of polymer materials. For example, the halogenated compounds mainly act in the gas phase [6]. While intumescent flame retardant (IFR) works by free radical suppression in the gas phase and char forming in the condensed phase [7,8]. Comparatively, the presence of nanofillers can improve flame retardancy via forming physical barriers, originating from the formation of a network structure in polymer matrix [9–12]. In addition, catalyzing carbonization of polymer is a novel promising method to improve flame retardancy of polymer materials [13].

The in situ formation of stable protective layer covering the entire sample surface without openings or cracks is the key to obtain polymer materials with good flame retardancy, which strongly depends on finding new ways to build much stronger and more stable network [14]. The combination of nanofillers with IFR or carbonization catalyst is an effect way to reinforce the network in polymer matrix [15–17]. Ma et al. found that the addition of functionalized carbon nanotube (CNT) by grafting IFR could improve flame retardancy of ABS resin, resulting from better dispersion of CNT and better dense char formed [16]. Yu et al. demonstrated that the combination between CNT and Ni_2O_3 improved the flame retardancy of polyethylene, due to good dispersion of CNT and carbonization of degradation products catalyzed by Ni_2O_3 [17]. The combination between fillers with different geometrical dimensions is another way to construct a three-dimensional (3D), compactly interconnected network [18–20]. More importantly, this strategy is a promising way to fabricate multifunctional

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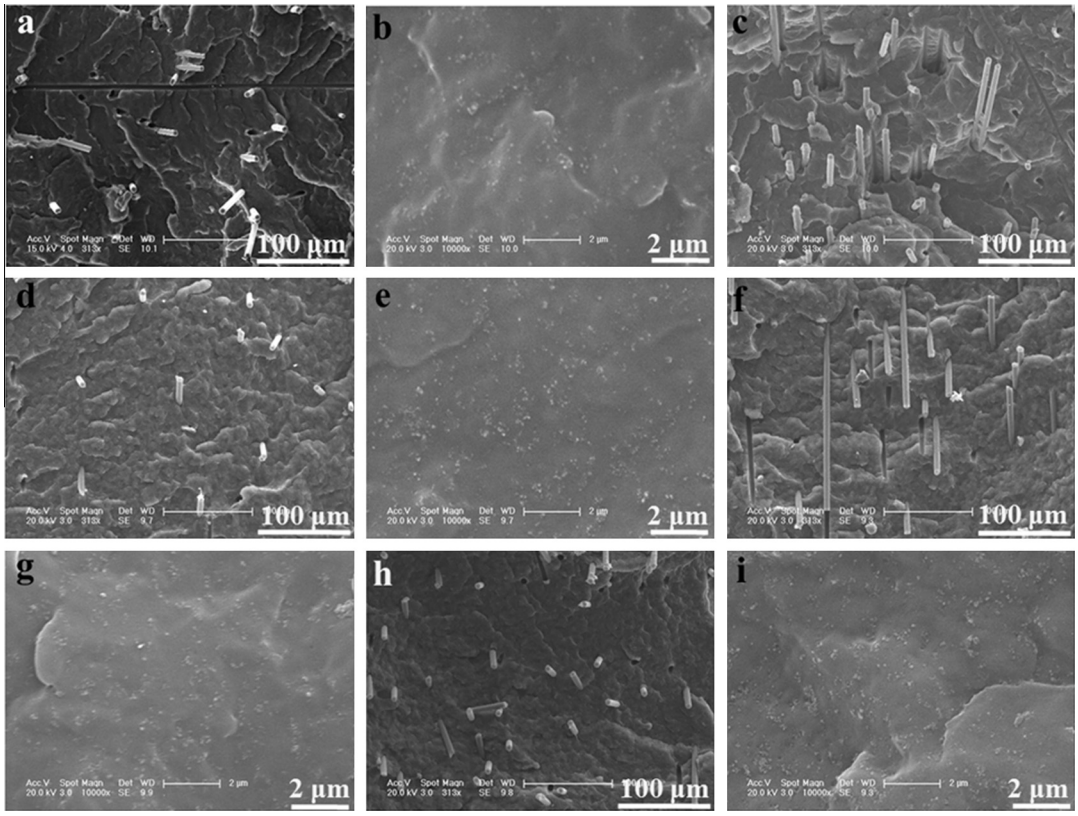

Fig. 1. FE-SEM micrographs of the brittle-fractured surfaces of PP and its composites: (a) 3CF, (b) 5CB, (c) 8CF, (d and e) 1CF5CB, (f and g) 3CF5CB and (h and i) 5CF5CB.

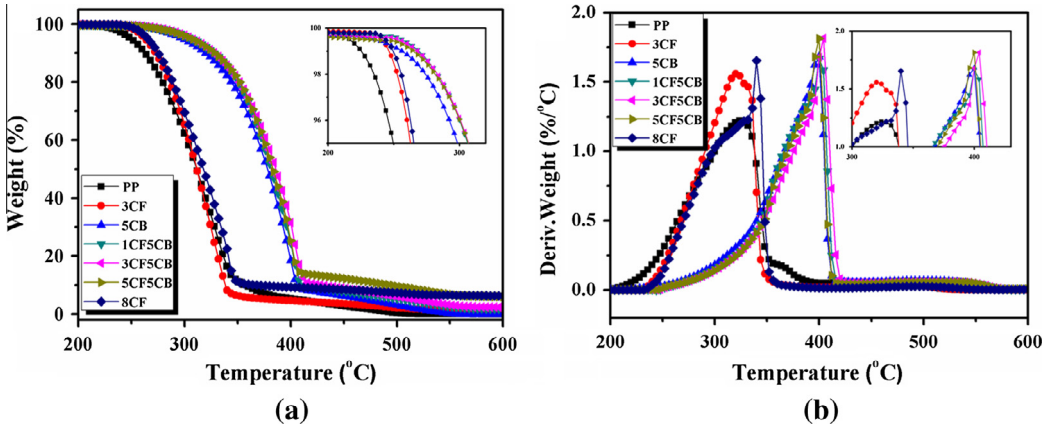

Fig. 2. TGA (a) and DTG (b) curves of neat PP and its composites in air at the heating rate of 10 °C/min.

Table 1
Summary for TGA results of PP and its composites under air atmosphere.

Sample	CF (wt%)	CB (wt%)	$T_{5wt\%}$[a] (°C)	T_{max}[b] (°C)
PP	0	0	250	325
3CF	3	0	263	320
5CB	0	5	299	398
1CF5CB	1	5	306	401
3CF5CB	3	5	307	404
5CF5CB	5	5	307	400
8CF	8	0	265	341

[a] $T_{5wt\%}$ represented the temperature at which 5 wt% weight loss rate occurred.
[b] T_{max} represented the temperature at which the maximum weight loss rate occurred.

polymer composites (e.g., electrical and thermal conductivity and electromagnetic shielding).

Herein, we report a novel way to improve the flame retardancy of polypropylene (PP)/CF composites by adding CB as functional nanofillers in the benefit of other properties at the same time. As we know, the addition of CF can improve mechanical properties of PP. Besides, carbon black (CB) is one of the widely used nanofillers, which is cheap and permanent conductivity. More importantly, CB nanoparticles possess trapping free radical character, which can be used to block degradation of polymers in condensed phase and form crosslinking structure [21] to improve flame retardancy and thermal stability of PP. Our previous report found that the addition of CB (5 wt%) could improve the thermal stability and flame retardancy of polypropylene (PP) to some extent [22].