



Review

Recent progress on preparation and properties of nanocomposites from recycled polymers: A review

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ABSTRACT

Currently, the growing consumption of polymer products creates the large quantities of waste materials resulting in public concern in the environment and people life. Nanotechnology is assumed the important technology in the current century. Recently, many researchers have tried to develop this new science for polymer recycling. In this article, the application of different nanofillers in the recycled polymers such as PET, PP, HDPE, PVC, etc. and the attributed composites and blends is studied. The morphological, mechanical, rheological and thermal properties of prepared nanocomposites as well as the future challenges are extensively discussed. The present article determines the current status of nanotechnology in the polymer recycling which guide the future studies in this attractive field.

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1. Introduction

1.1. Polymer recycling

Polymers are the most widely used materials in various fields due to their valuable properties such as good mechanical properties, low density, rather low cost, and also ease of processing (Ansari and Alikhani, 2009; Rahimi and Shokrolahi, 2001). The total production of plastics is more than 230 million tonnes per year which will reach to 400 million tonnes in 2020 based on a more conservatively annual growth rate of about 5% (Braun, 2004; Simoneit et al., 2005).

Every year, large quantities of waste polymers are produced from industrial, agricultural and household activities. It has been reported that plastics make up more than 12% of municipal solid waste stream, a dramatic growth from 1960, when plastics were only 1% of the waste stream (<http://www.epa.gov/osw/conservation/materials/plastics.htm>). The new environmental, economic, and petroleum considerations have induced the scientific communities to increasingly deal with polymer recycling (Fall et al., 2010; Salmiaton and Garforth, 2007, 2011; Taurino et al., 2010).

The efficient treatment of waste polymers is still a difficult challenge. The traditional methods such as combustion or burying underground show a negative effect on the environment like formation of dust, fumes and toxic gases in the air, and the pollution of underground water and other resources. The recycling process is the best way to manage the waste polymers. There are various techniques for recycling of waste polymers including primary

recycling, mechanical recycling, chemical or feedstock recycling and energy recovery (García et al., 2009; Sadat-Shojai and Bakshandeh, 2010; Zhang et al., 2009b). The recycling rate for different types of plastic significantly varies, leading to an overall recycling rate of only 8% or 2.4 million tons in 2010 (<http://www.epa.gov/osw/conservation/materials/plastics.htm>).

However, there are some main problems for polymer recycling such as separation (Burat et al., 2009). For example, PVC bottles are difficultly identified from PET ones, but one stray PVC bottle in a melt of 10,000 PET bottles can ruin the whole batch. For ease of separation, most manufacturers determine the type of plastics by the numerical coding system created by Society of Plastics Industry in 1980s (<http://www.epa.gov/osw/conservation/materials/plastics.htm>). The identification codes can be found at the bottom of most plastic packaging. Table 1 shows the identification codes and some household applications of commonly used polymers. However, plastic tarps, pipes, toys, household coverage, and a multitude of other products do not fit into the numbering system. So, there are not usually collected as well as the thousands of different polymers. Moreover, after several processing cycles, the structure of polymer is degraded introducing the poorer mechanical properties than those of a virgin one (Goto et al., 2006; Oromiehie and Mamizadeh, 2004). To overcome these limitations, it seems that the easiest way to recycle the waste plastics is development of blends and composites.

1.2. Why nanotechnology?

Nanotechnology is assumed as one of the key technologies in the recent century (Shabani et al., 2012, 2011a, 2011b, 2009). We can obtain the substantial enhancements of mechanical, thermal,

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Table 1

The identification code and some household applications of most consumed polymers.

Polymer	Identification code	Applications
PET	1	Fizzy drink bottles, Waterproof packaging
HDPE	2	Milk, oil and detergent Bottles, toys and plastic bags
PVC	3	Food trays, cling film, liners, blister packages
LDPE	4	Carrier bags and bin Liners, shrink wrap, garment bags
PP	5	Margarine tubs, Refrigerated containers, bags, bottle tops, carpets, some food wrap
PS	6	Yoghurt pots, foam Plastic cutlery, protective packaging for electronic goods and toys, throw-away utensils

optical and barrier properties using the nanofillers (Frounchi et al., 2006; Shahabadi and Garmabi, 2012; Zare and Garmabi, 2012a; Zare et al., 2011). The nano-additives increase the interphase surface of components and superficial area/volume ratio leading to improvement of overall performances. In comparison to traditional micro-fillers, very low loading of nanoclay is sufficient to achieve the excellent development of properties without substantially increasing the density and cost or reducing the light transmission properties of base polymer (Jafari et al., 2012; Ramezani-Dakhel and Garmabi, 2010; Zare and Garmabi, 2012b).

Further, the reduced melt strength of recycled polymers in extrusion process causes the inconsistency of material after leaving the die which makes the production of sheets or profiles impossible (Hamzehlou and Katbab, 2007; Kráčalík et al., 2007b). Also, reprocessing of waste PET with very small intrinsic viscosity is not feasible (Kráčalík et al., 2007c). Nanofillers can increase the melt strength and viscosity of recycled polymers in addition to improvement of various properties. The recent studies on polymer recycling by nanofillers are presented in Table 2.

In this review paper, a comprehensive study on the application of nanofillers in the recycling process of polymers, composites and blends is carried out. Moreover, the future challenges in this area are discussed which can help the researchers in the potential works.

2. Results and discussion

2.1. Recycled polyethylene terephthalate (rPET)

2.1.1. Nanoclay content

Hamzehlou et al. have found the optimal nanoclay (DK2) content of 3 wt.% for tensile strength of both recycled and virgin PET nanocomposites (Hamzehlou and Katbab, 2007). However, it was clearly observed that all samples prepared from rPET showed the higher tensile properties, compared to virgin PET (vPET). Also, the onset of thermal degradation has been delayed for rPET nanocomposites composed of 3 and 5 wt.% of nanoclay. It exhibited the enhanced melt elastic modulus and pseudo solid-like behavior of nanocomposite at low shear frequencies compared to unfilled PET indicating the formation of nanoscopic network structure by the clay platelets. At low shear frequencies, the samples containing 3 and 5 wt.% of nanoclay demonstrated the higher storage modulus while more Newtonian behavior was shown in the samples with nanoclay concentration of lower than 5 wt.%. The oxygen permeation of virgin and recycled PET nanocomposites is observed in Fig. 1. The permeation of neat rPET was larger than neat vPET, due to the smaller chain size of rPET; but, the addition of nanoclay

Table 2

Recent studies on the polymer recycling via nanotechnology.

Polymer	Nanofiller	References
PET	Nanoclay	Basilia et al. (2011), Bizarria et al. (2007), Giraldi et al. (2008), Hamzehlou and Katbab (2007), Karabulut (2003), Kráčalík et al. (2007a), Kráčalík et al. (2007b, 2007c) and Pegoretti et al. (2004)
PET/rubber	Nanoclay	Kelnar et al. (2010)
PET/PMMA	Nanoclay	Kerboua et al. (2010)
PET/ABS	SiO ₂	Shi et al. (2011)
PP	Nanoclay	Cengiz (2008), Tri Phuong et al. (2008)
PP	CaCO ₃	Elloumi et al. (2010)
PP	CNTs	Gao et al. (2011)
PP/HIPS	Nanoclay	Mural et al. (2011)
HDPE	Nanoclay	Hill (2005) and Lei et al. (2007)
HDPE	Graphene	Jannapu Reddy (2010)
HDPE/baggase	Nanoclay	Hemmasi et al. (2011)
PVC	Nanoclay	Yoo et al. (2004)
PVC/PP	CaCO ₃	Andričić et al. (2008)
PS	Nanoclay	Liu et al. (2007)
PMMA	Nanoclay	Martin et al. (2008)
PBT/glass fiber	SiO ₂ , MMT, mica	Zhang et al. (2009a)

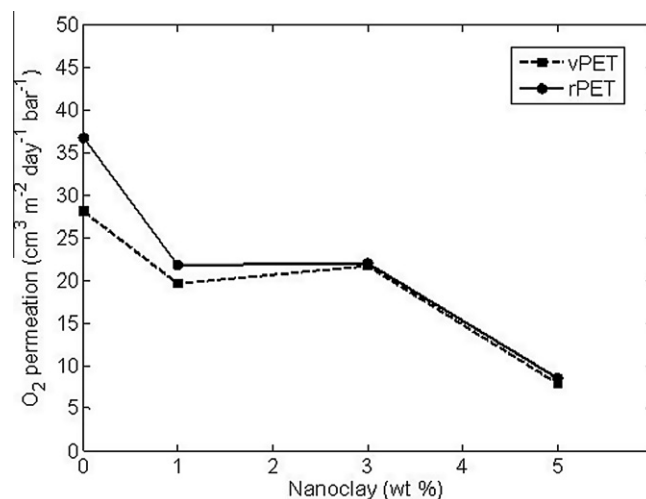


Fig. 1. The oxygen permeation of virgin and recycled PET nanocomposites at different nanoclay content (Hamzehlou and Katbab, 2007).

decreased the permeation in both rPET and vPET nanocomposites and the permeation became similar for both nanocomposites at higher contents of nanoclay (>3 wt.%).

Basilia et al. (2011) also reported that the 5 wt.% of synthesized Philippine MMT (Na-MMT) offered the best improvement of tensile properties. Furthermore, Giraldi et al. (2008) have found that the optimized values of strength and toughness were obtained at 2.5 wt.% of nanoclay instead of 5 wt.%.

Pegoretti et al. (2004) and Bizarria et al. (2007) prepared the rPET/organoclay nanocomposites at several nanoclay content (1, 3 and 5 wt.%). Both works suggested the highest stiffness and tensile strength at 5 wt.% of nanoclay. In Bizarria study, T_g slightly decreased by the clay content, may be due to clay agglomeration which occurred above a critical clay loading (Chang et al., 2005; Haddad and Lichtenhan, 1996; Xu et al., 2002).

Karabulut compounded the rPET with commercial nanoclay (Cloisite 30B) in the contents of 1, 2, and 5 wt.% (Karabulut, 2003). The mechanical properties such as tensile, flexural and impact results showed the highest improvement in the clay content of 2 wt.%.

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