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Synergistic Effects of Carbon Nanotubes and Exfoliated Graphite Nanoplatelets for Electromagnetic Interference Shielding and Soundproofing

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ABSTRACT: Polypropylene/carbon nanotube/exfoliated graphite nanoplatelet (PP/CNT/xGnP) composites have been fabricated to evaluate their electromagnetic interference shielding effectiveness (EMI SE) and soundproofing. An EMI SE of 36.5 dB at 1250 MHz was measured for the 80/10/10 wt % PP/CNT/xGnP composite; its sound transmission loss was more than 5 dB higher than that for pure PP at low frequencies (520–640 Hz). These results indicate simultaneous EMI SE and soundproofing. Transmission electron microscopy was used to study the microstructure and to probe synergetic effects between the CNTs and xGnPs. © 2013 Wiley Periodicals, Inc. J. Appl. Polym. Sci. 130: 3947–3951, 2013

KEYWORDS: nanotubes; graphene and fullerenes; nanostructured polymers; composites; inorganic polymers; morphology

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INTRODUCTION

The public has been increasingly concerned about the possibility of health risks associated with many types of new pollutants, such as electromagnetic interference (EMI) and noise in automobiles.[1–3] EMI is radiated by automotive electrical and electronic systems, and exposure to continuous automotive noise can be irritating. In some cases, such exposure can lead to stress responses.[4–6] Hence, automotive engineers are often faced with questions: what are the effects of EMI and noise on human health, and how do we reduce or eliminate these pollutants?

Conventional composites have been used to improve the performance of various automotive parts and structures. Composite materials are being used to reduce weight and thereby improve fuel efficiency.[7–11] Recently, automobile companies have tried to reduce EMI and noise by using composites. Electronic systems are being increasingly placed in automobiles as technology advances. However, placing many electronic equipments into a restricted space make it difficult to prevent interactions between EMI sources. Composite materials have been used to provide EMI shielding to prevent system malfunctions.[12] To reduce noise in cars, various sound absorbing and insulating materials have been developed; these include polymers mixed with nanofillers. Lee et al. investigated the soundproofing effect of nanoparticle-reinforced polymers such as acrylonitrile–butadiene–styrene/carbon nanotube (ABS/CNT) composites.[13] These composites had better soundproofing performance than pure ABS.

The ongoing development of economical and high-performance polymer composites has dramatically increased their applications in the automotive industry. There is a need for materials that will simultaneously reduce EMI and noise, and composites can do this.

The aim of this work was to verify the dual performance for EMI shielding and soundproofing of composites containing CNTs and exfoliated graphite nanoplatelets (xGnPs). We report the fabrication of PP/CNT/xGnP composites and their evaluation for EMI shielding effectiveness (SE) and soundproofing of automotive parts. Additionally, the microstructures of the composites were investigated by transmission electron microscopy (TEM) to evaluate a micro-mechanism for the improvement of EMI SE and soundproofing properties.

EXPERIMENTAL

Materials

Polypropylene (PP) has attracted a tremendous amount of attention as thermoplastic polymers; it is used in

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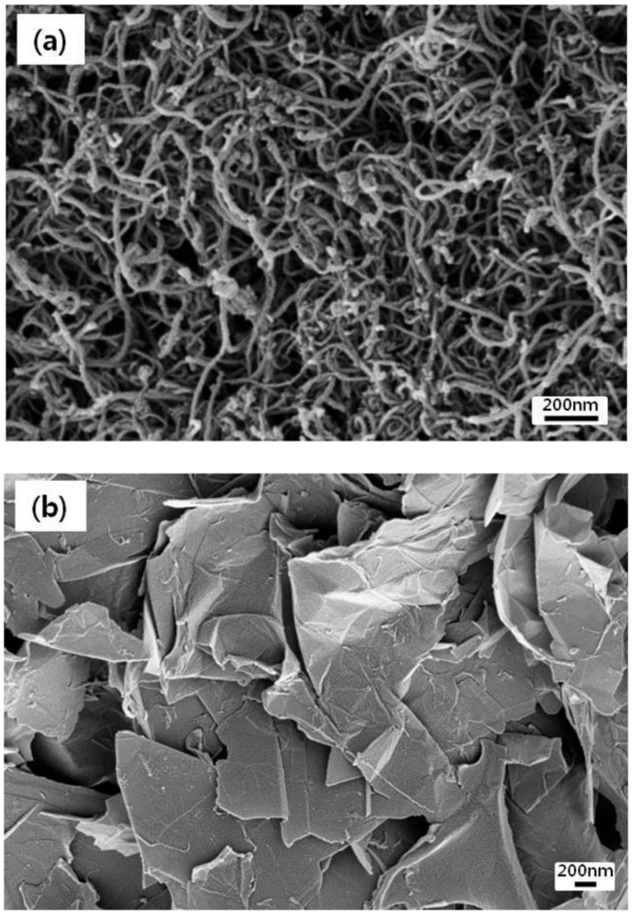

Figure 1. Field-emission scanning electron microscopy (FE-SEM) images of (a) CNT and (b) xGnP particles. (a) CNTs are the one dimensional fibrous structure. (b) xGnPs are the two dimensional planar structure.

automobiles, electronics, and packaging.[14–16] CNTs are considered ideal fillers for polymers because of their high aspect ratios, electrical conductivities, EMI SE, and good mechanical strengths [Figure 1(a)].[17–19] xGnPs is one of the most competitive materials to CNTs [Figure 1(b)].[20–28]

In this study, PP (HJ400, Samsung Co., Korea) was selected as the polymer matrix. Two kinds of fillers were prepared as nano reinforcing materials: CNTs (MWCNT CM-95) and xGnPs (xGnP-M-15). Both were supplied by Hanwha Nanotech Co., Korea under license from XG Sciences, USA.

Preparation of Composites

A homogeneous dispersion of the nanofillers and strong interaction between the matrix and the nanofiller particles are important requirements for achieving high-performance materials.[29] For this study, the composites were prepared by solution blending followed by hot-pressing, as discussed below.

For a typical preparation of PP composite, 80/10/10 PP/CNT/xGnP composite was made of 80 wt % PP with 10 wt % CNT and 10 wt % xGNP, respectively. The CNTs and xGnPs were introduced into a 1000-mL flask equipped with magnetic stirrer. After addition of 100 mL of xylene, the mixture was stirred at 130°C and 300 rpm for about 2 h. Then the well-dispersed black suspension was poured to a beaker for cooling, and the mixture of PP/CNT/xGnP was filtered. The retained precipitate was evaporated at 100°C in an oven for 5 h to eliminate the xylene. Finally, the composites were molded by heating in a press at 230°C and 30 MPa.

Characterization

The electrical resistivity of the composites is determined according to ASTM D4496, using an SR-2000NW four-point probe instrument (Chang min-Tech. Co., Sungnam-City, Korea).

The EMI SE test was conducted according to ASTM D4935-99 using a network analyzer (Agilent N5230A) over a frequency range of 30 MHz to 1.5 GHz.[30–33]

Sound transmission loss (STL) values were measured according to ASTM E1050-98 at room temperature by the impedance tube method using Brüel & Kjær (B&K) standing wave tube. Measurements were made at low frequencies, i.e., 520–640 Hz.[34]

TEM was used to evaluate the dispersion of the xGnP/CNT hybrid fillers in the PP matrix. A Zeiss EM 912 Omega instrument was used, operating at an accelerating voltage of 120 kV.

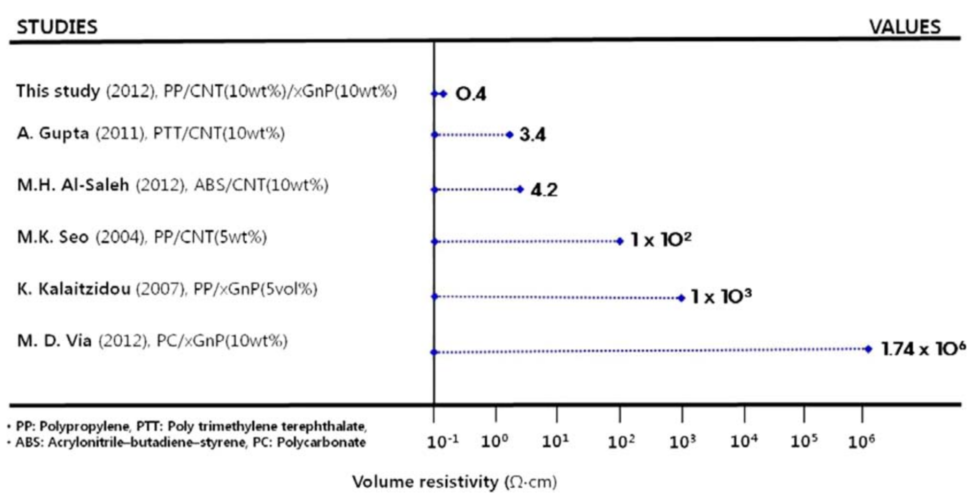

Figure 2. The volume resistivity of various types of polymer/nanofiller composites. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

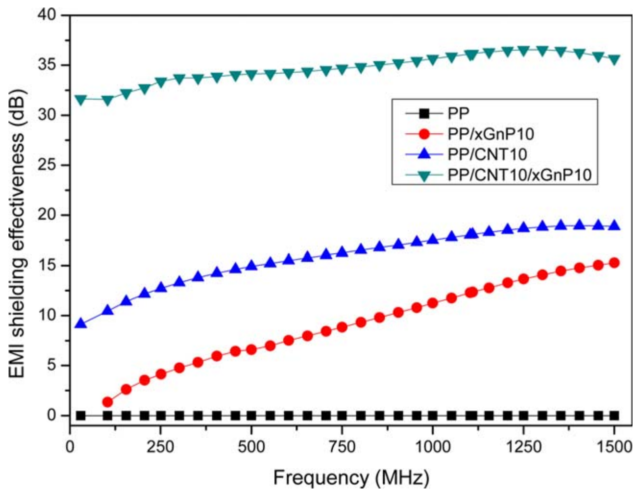

Figure 3. EMI SE of nanocomposites as functions of frequency and filler content. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

A thin layer, about 70 nm thick, was sectioned from the crystallized sample at −100.0°C using an ultra-microtome equipped with a diamond knife.

RESULTS AND DISCUSSION

Electrical Properties

In general, high conductivity of a material, its magnetic properties, and the small particle size of the filler are the main parameters that affect the shielding capabilities. There have been several reports that composites having lower electrical resistivity also possessed better EMI SE.[35–40] For this work, the electrical resistivity was measured using the four-point probe method. Figure 2 shows the volume resistivity of various types of polymer/nanofiller composites.[37,41–43] Because the electrical properties of the composites reported herein were better than those reported for other composites, it was expected that they would also have good EMI SE.

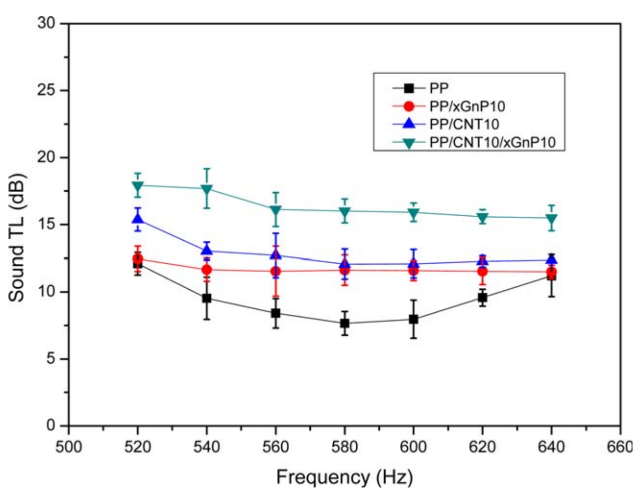

Figure 4. STL of PP and PP/nanofiller composites as functions of frequency and filler content. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

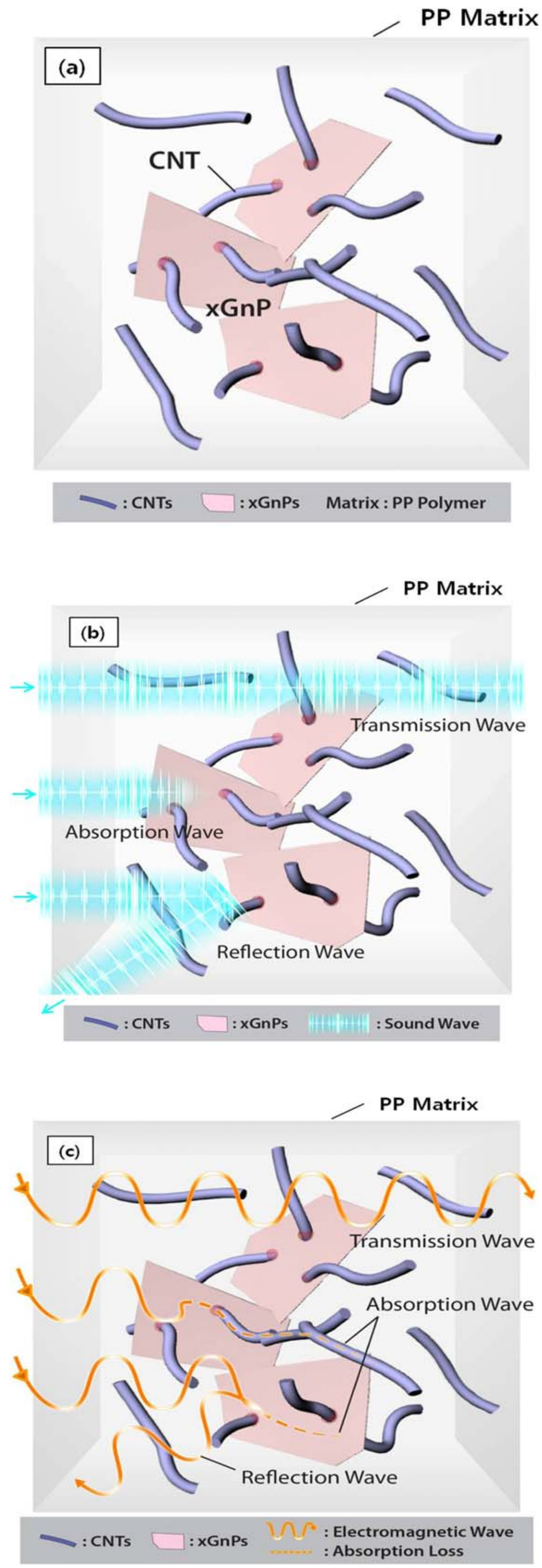

Figure 5. (a) Illustrations of the morphology of nanocomposites mixed CNTs and xGnPs in the PP matrix (b) The internal behaviors of nanocomposites for soundproofing. (c) The internal behaviors of nanocomposites for EMI shielding.[Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

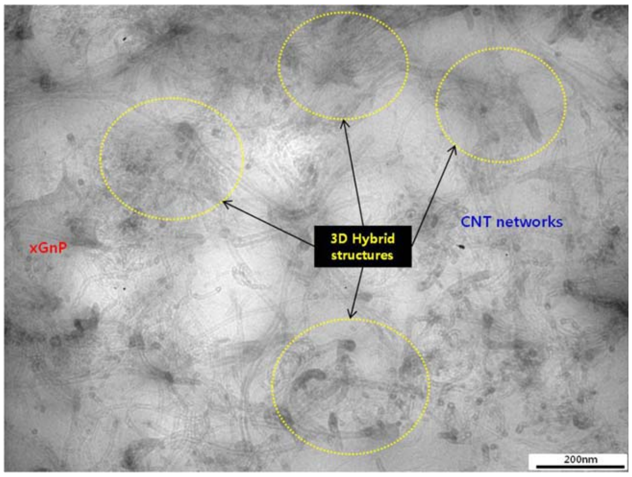

Figure 6. TEM images of the 80/10/10 PP/CNT/xGnP composite showing CNT networks, xGnP particles and 3D hybrid structures. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Electromagnetic Interference Shielding Effectiveness

The EMI SE of a material is defined as the ratio of the incident to the transmitted power of an electromagnetic wave. It is usually expressed in decibels (dB). Figure 3 compares the change in EMI SE for the PP/CNT/xGnP, PP/CNT, and PP/xGnP composites as a function of filler loading. There was a remarkable increase in EMI SE with increasing CNT and xGnP loadings. In particular, the 80/10/10 PP/CNT/xGnP composite provided a shielding of 36.5 dB at 1250 MHz. This composite also had a considerably higher EMI SE than the PP/CNT and PP/xGnP composites. It is expected that the 80/10/10 PP/CNT/xGnP composite could be used in commercial applications because the EMI SE exceeds the required minimum of 20 dB.[30,40,44] Moreover, it is evident that the EMI SE was independent of frequency in the measured region.

Soundproofing Properties

The use of soundproofing materials is one of the most popular techniques for noise reduction. The STL is a common means of the soundproofing property of a material, where a larger STL indicates a better soundproofing material.[45] The STL is defined as the difference between the sound power levels of the incident sound and the transmitted sound.[46,47] STL intensity is reported in units of dB.

Figure 4 compares the soundproofing properties of the 80/10/10 PP/CNT/xGnP composite with those of PP, PP/CNT, and PP/xGnP as a function of frequency. The results show that the 80/10/10 PP/CNT/xGnP composite was much better at soundproofing than pure PP and the other materials at all frequencies tested. At 580 Hz, the 10 dB STL was much higher than that for pure PP, which is used for many automobile parts.

Thus, PP mixed with CNT/xGnP can potentially replace PP and other competitive materials as an improved soundproofing material for automotive parts.

Microstructure Analysis

The 80/10/10 PP/CNT/xGnP composite simultaneously improved the EMI SE and soundproofing through synergetic effects between the CNT and xGnP particles (Figure 5). TEM was used to explore this synergy.

It is well established that EMI SE is affected mainly by the formation of conductive networks in the PP matrix. Increases in CNT and xGnP filler loadings increase the number of interconnections between the CNT and xGnP particles in the PP matrix. These interact with incident radiation and lead to a much higher EMI SE.[30]

TEM was used to evaluate the dispersion state, nano morphology, and the unique synergistic mechanism of CNTs and xGnPs in the PP matrix. The morphology and structure of the 80/10/10 PP/CNT/xGnP composite are shown in Figure 6. The xGnP particles were dispersed homogeneously in the PP matrix, with no large clusters of CNTs or xGnPs. CNTs were homogeneously dispersed and attached to xGnPs layers, which formed conductive networks between the CNTs. This connectivity may be responsible for the improved EMI SE. The PP chains were tangled and wrapped around the one-dimensional structure of the CNTs and the two-dimensional structure of the xGnP platelets. The regions within the dashed circles indicate the CNT/xGnP hybrid fillers, and the light areas correspond to the PP matrix. The two-way interaction between the CNTs and xGnPs in the PP matrix improved the transformation of sound energy into heat energy and thereby enhanced the soundproofing effect.

Thus, the synergistic effect between the homogeneous dispersion and strong adhesion of the CNTs and xGnP platelets simultaneously improved the EMI SE and soundproofing performances of the composites.[29,43,48]

CONCLUSIONS

In conclusion, the 80/10/10 PP/CNT/xGnP composite reported here exhibited improved EMI SE and soundproofing performance. A dual-performance composite containing CNTs and xGnPs was demonstrated for the first time. The EMI SE was 36.5 dB at 1250 MHz, which suggests that this composite could be used in commercial applications. The 80/10/10 PP/CNT/xGnP composite also had remarkably improved soundproofing properties: the 10 dB STL at 580 Hz was much greater than that for pure PP, suggesting that the composite could replace other competitive materials, such as PP, which are used as soundproofing materials in many automobile parts.

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