Investigation of mechanical and EMI shielding performance of PP/CNT/Glass fiber microcellular foam

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ABSTRACT

Polypropylene (PP)/Multiwall-Carbon-Nanotube (CNT) nanocomposites and PP/CNT/Glass fiber (GF) hybrids were foamed using supercritical carbon dioxide (CO_2) through a batch foaming process. By incorporating CNTs in the matrix, the average cell size was reduced to less than one-second that of neat, and cell density increased. By incorporation of CNTs, electrical conductivity and EMI shielding effectiveness increased for unfoamed and foamed PP/CNT3 samples. Tensile properties of fiber-filled hybrids revealed that by increasing the fiber content, young modulus and tensile strength increased for unfoamed samples and decreased for foams. The compression test of hybrid foams showed that by loading nanotubes and glass fibers, compressive mechanical properties increased.

INTRODUCTION

In the last decade, nanocomposite foams have attracted a great deal of interest in numerous research fields due to their superior strength-to-density ratio, impact, electrical, and thermal properties [1]. Recently, polymeric composite foams containing carbonaceous fillers have attracted electromagnetic interference (EMI) shielding applications [2]. As electronic devices and communication instruments are being fully-fledged, it is expected to be crucial to reduce electromagnetic pollutions. Compared to the metal-based EMI shielding materials, carbonaceous polymer composites and their foams have some advantages, including lightweight, easy processing, and broad absorption bandwidth [3]. Light weighting of the EMI shielding materials has been applied through various procedures. One of the practical methods to achieve this purpose is Solid-state batch foaming. As a matter of fact, micro and nano-sized fillers could ameliorate and enhance electrical conductivity and shielding features of polymer foams in which these properties depend on filler size, shape, concentration, and their aspect ratios.

Some restrictions such as poor tensile strength, poor surface quality and low thermal and dimensional stability for polymeric foams limited their engineering usage. Improving foams' mechanical properties has attracted a great deal of interest in the last decades [1,4]. Fibers can act as the most potential enhancer, and there is now a substantial body of literature that investigated their influence on foams. The presence of fibers in the polymeric foams can adjust the final properties; indeed, fibers not only significantly increase tensile and compression modulus as well as strength but also can control the nucleation and growth rate of cells.

OBJECTIVES

The current study aims to take advantage of simultaneous benefits of the GF and CNT incorporation in both EMI shielding performance and mechanical properties improvement. To do so, there is a great need to investigate the microstructural properties; hence, the effect of microcellular foaming and weight fraction of the components on the solids and foams' EMI SE, EC, and mechanical properties were examined.

MATERIALS & METHODS

RPX-120L grade of PP was purchased from Jam Petrochemical Co. CNTs were supplied by NanocylTM, Belgium. Taiwan glass 203P grade Glass fibers were used in this study as the reinforcement. The PP/MWCNT/GF hybrids were prepared by melt compounding in a Brabender. A batch foaming process via supercritical CO_2 was used to produce cellular structure in the nanocomposites and the hybrids. Samples were first placed in an autoclave vessel containing a syringe pump. Then, the autoclave was fed by a CO_2 capsule to reach the saturation pressure of 170 bar. After the saturation time (60 min), foams were produced through a fast pressure drop at 134 ºC.

RESULTS

Figure 1 shows SEM micrographs of the nanocomposite and hybrid foams with various carbon nanotube and GF contents. It is evident that average cell size decreased with an increase in nanotube content. However, the foam density and cell density were enhanced. The cellular structure improvement by incorporating CNTs could be attributed to enhancing foaming heterogeneous cell nucleation via loading the nanotubes, which increase nucleation sites [3]. It is worthy of mention that the presence of nanotubes could itself improve melt strength, which could be considered as another reason for the improvement in cellular structure. In the presence of GF, the average cell size increased, and the cell density first decreased and then increased by enhancing the fiber content compared to the nanocomposite foams without glass fiber. It is noteworthy that the larger cells were formed around the fibers, and the number of these large cells increased as the amount of fibers increases. Also, the cells adjacent to these large cells have been significantly reduced. To sum up, these alterations in cellular characteristics could be attributed to; (I) boosting the number of heterogeneous nucleation sites, (II) reduction in gas portion required for the growth of the smaller cells due to the absorbing a great deal of blowing agent into the matrix-fiber interface, and (III) coalescence prevention owing to the increment of melt strength.

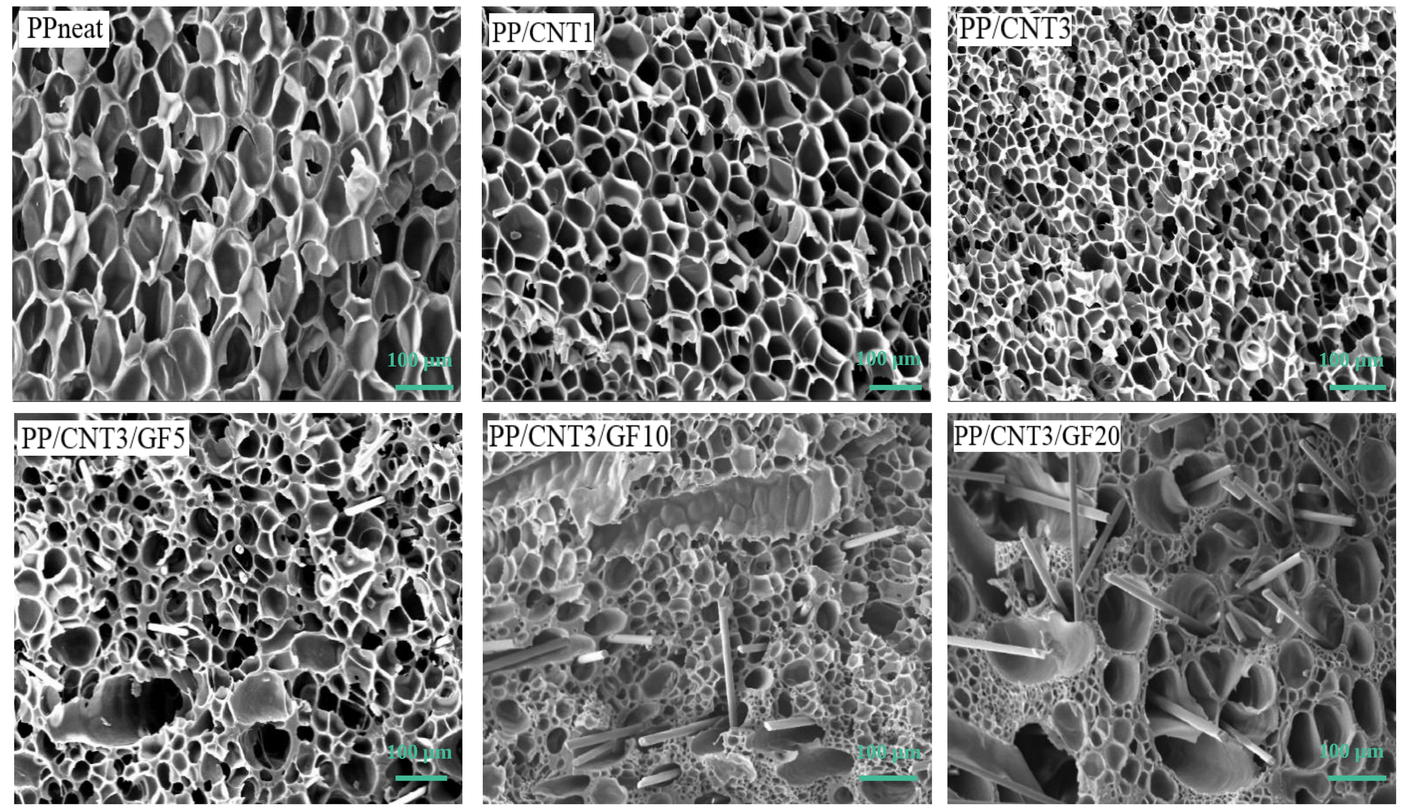

Figure 1. SEM micrographs and cell size distribution of the produced foams. All photos have the scale bar of 100 micrometers

Volume DC electrical conductivity of solid composites as a function of filler content, as well as the influence of microcellular cell structure on the electrical conductivity of nanocomposites are shown in figure 2a. By the incorporation of CNTs in both solid and foamed samples, the electrical conductivity (EC) increased. Enhancement of the EC by increasing the number of nanotubes can be attributed to increasing the contact surface of carbon nanoparticles, thus establishing the path of movement and facilitating the movement of electrons from one place to another. However, conductivity decreased after introducing the cellular structure. This result stems from the supposition that porous structures can act as obstacles for electron travel and increase the distance of adjacent nanoparticles.

The electrical conductivity potentially endows lightweight nanocomposite foams with good electromagnetic interference (EMI) shielding property. The EMI shielding of nanocomposites and their microcellular foams at the X-band were measured (Figure 2b). The EMI SE of PP/CNT nanocomposites increased up to ~11 dB at 3 wt % CNT loading. After the volume expansion by ~10 times, however, the EMI SE of nanocomposite foams slightly decreased. The reason for the difference in EMI SE between the two samples was mainly due to the obvious decrease in electrical conductivity and the actual thickness of microwave radiative transfer in the foamed sample. Therefore, the significant reduction of sample thickness by expansion would inevitably decrease the EMI SE of nanocomposite foam. Figure 2c summarizes the contribution of SE(Absorption) and SE(Reflection). The introduction of the microcellular structure was verified to further increase the contribution of SE(Absorption) to SE(Total), where about 92.2% electromagnetic energy was absorbed by the microcellular foams, suggesting the obvious increased absorbing ability of samples with the presence of microcellular structure.

The specific EMI shielding efficiency was calculated on the basis of the rate of total EMI shielding efficiency and the sample density, and the results are shown in figure 2d. Owing to the much lower density of the foamed hybrids, the specific EMI shielding efficiency, which represents the material utilizing efficient, would be higher than the solid counterparts. These results demonstrated that the foaming process dramatically improved the specific EMI SE of PP/CNT nanocomposites.

The impact of various fiber concentrations on both solids and foams' mechanical properties was explored and depicted in figure 3a. The elastic modulus and yield stress increased after the incorporation of the nanoparticles. However, both the ultimate tensile strength and the elongation at break decreased. These changes could be attributed to filler interaction with the matrix and the effect on the crystalline structure. It is also observed that by adding fibers to the system, the modulus and yield stress of the hybrids increased, and the elongation at break and toughness of the reinforced nanocomposites decreased.

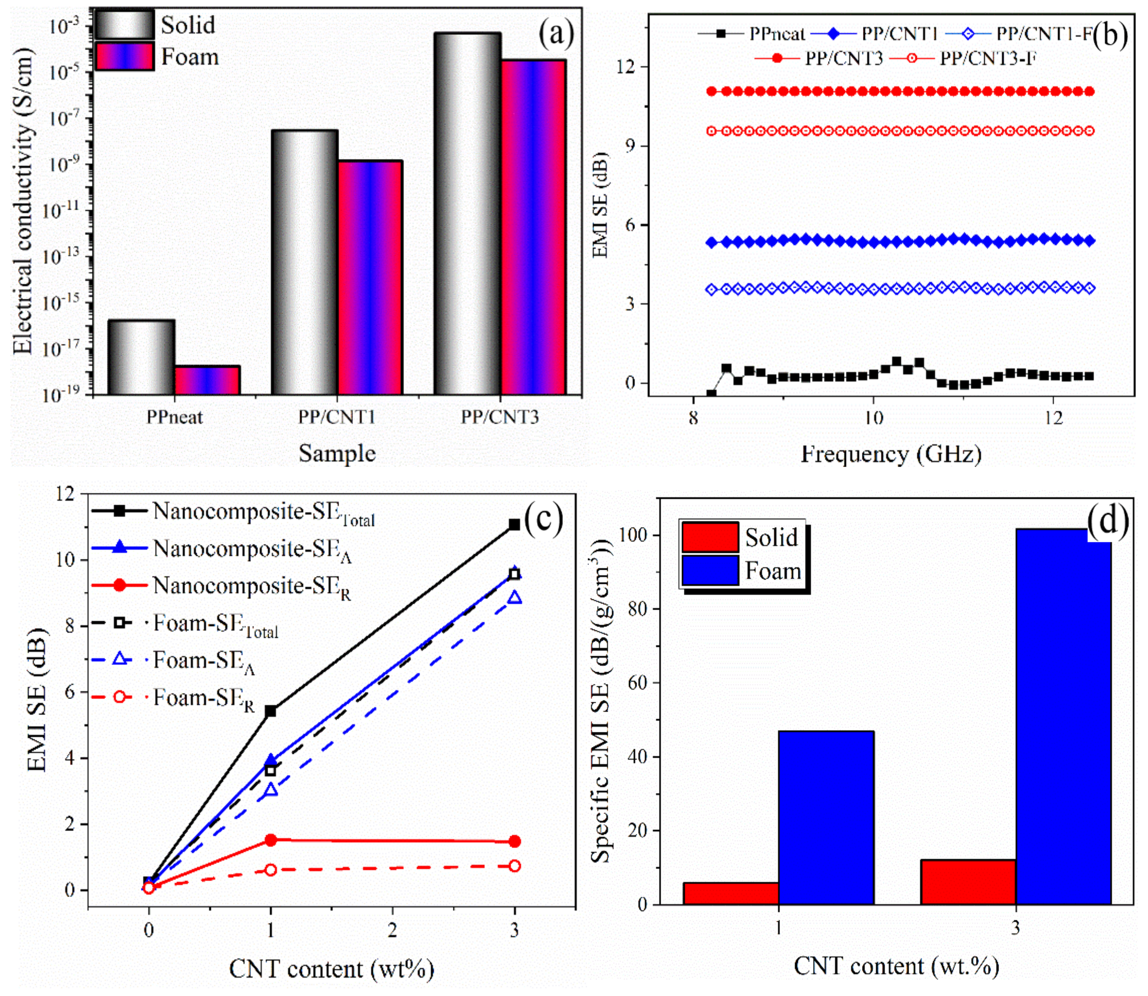

Figure 2. (a) Electrical conductivity (b) EMI shielding efficiency (c) SE_{Total}, SE_R, and SE_A of nanocomposites and foams (d) Specific EMI shielding efficiency

. These alterations can be attributed to the load distribution between the matrix and the fibers. Accordingly, more force was endured by the fibers. All mechanical properties were dropped, as expected, by incorporating a porous structure. Surprisingly, the tensile properties of hybrid foams reduced as fiber's content increased. According to the SEM micrographs of the foams, as the amount of fibers increased, the cells induced around the fibers enlarged. Fibers have an insignificant part in load-bearing since they are located in the center of the cells with loose fiber-matrix interfacial interaction.

The compressive strength of the nanocomposite foams are presented in Figure 3b. By increasing the fibers' content, Young's modulus and the collapse stress increased. These improvements in mechanical properties could have resulted from the presence of fibers with much higher strength and modulus, which enhanced the strength of the cell walls. Also, reducing the average cell size by increasing fiber content could be considered another motivation for improving the final compressive properties.

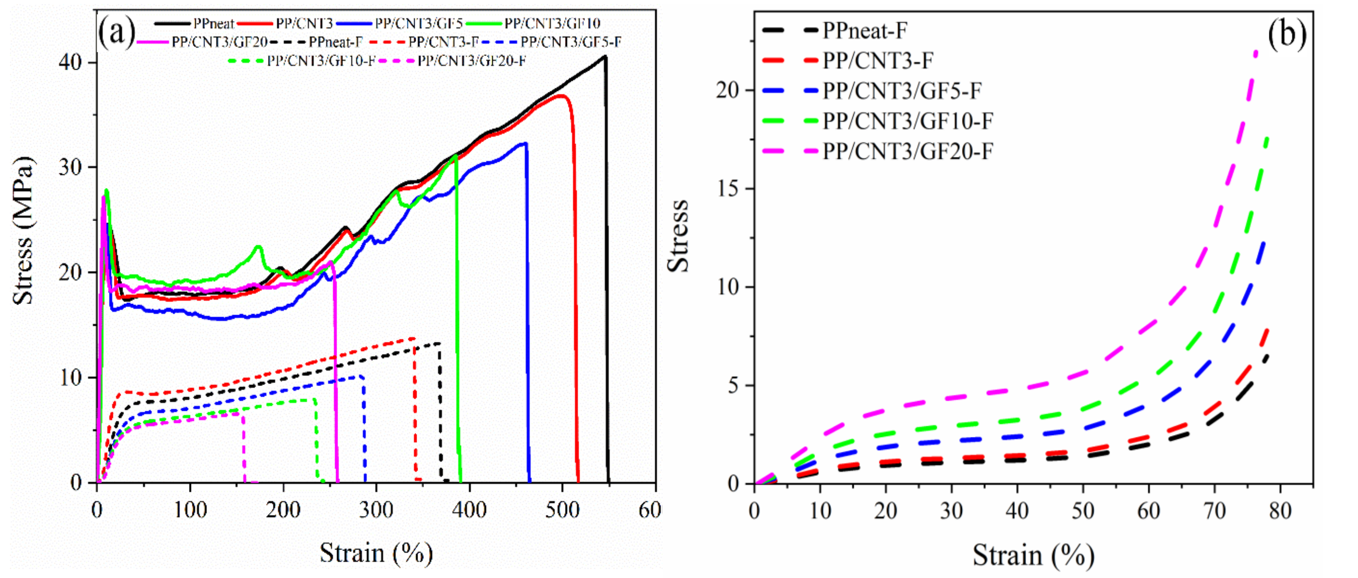

Figure 3. Stress-strain curves of the samples in (a) tensile and (b) compression mode

CONCLUSIONS

The main purpose of this work was to investigate electrical and EMI Shielding properties, as well as tensile and compressive mechanical properties of the PP/CNT and PP/CNT/GF foams. Results indicated that both EC and EMI SE increased with the addition of nanotubes and diminished by the formation of the cellular structure. By incorporating both fibers and nanotubes, the modulus and strength for solid samples increased, yet in microcellular foams, the tensile properties reduced as the fiber content enhanced. Hybrids' compressive mechanical properties indicated that Young's modulus and collapse stress increased by loading glass fibers.

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