ALIGNMENT CONTROL OF CARBON NANOFIBERS USING LIQUID CYSTALS

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Abstract

Carbon nanotubes (CNTs) and carbon nanofibers (CNFs) are used as reinforcements of polymers because of their excellent strength and stiffness. However, the efficiency as structural reinforcement depends on the ability to disperse uniformly, load transfer from the polymer matrix to the nanofillers and controlled nanofiller orientation. Among these critical issues, in this study, a technique for aligning the CNFs in a preferred direction was examined using a liquid crystalline (LC) polymer. The LC polymer used in this study exhibits nematic phase in which the direction of the long rod-shaped molecular axis can be aligned in one direction by applying electric or magnetic fields. The driving force due to the rotation of the long rod-shaped molecules was used to align the CNFs dispersed into the nematic LC polymer. The final goal of this study is to prepare CNF-aligned buckypapers.

1. Introduction

Because of their excellent mechanical, electrical and thermal and magnetic properties, carbon nanotubes (CNTs) and carbon nanofibers (CNFs) have been considered as a new form of carbon material. Researches on the mechanical properties have revealed that CNTs and CNFs can be potentially used as reinforcement fillers in polymer composite systems [1,2]. CNTs and CNFs are anisotropic in nature. Therefore, to take advantage of the nanofillers in their axial direction, the degree of alignment of the nanofillers in the polymer matrix is important to realize their high mechanical and functional properties.

Although many researches have been performed on nanofiller-dispersed polymer composites, the alignment of the nanofillers is usually random [3-5]. If the alignment of the nanofillers is achieved in a preferred direction, it may open the possibility of tailoring a desired mechanical property for nanofiller-dispersed polymer composites.

Liquid crystals (LCs) are anisotropic fluids, thermo-dynamically located between the isotropic fluid and the three-dimensionally ordered crystal [6]. In the case of nematic LCs (Fig.1), the direction of the long rod-shaped molecular axis can be easily aligned in one direction by applying electric or magnetic fields. The driving force due to the rotation of the long rod-shaped molecules of nematic LCs may be used to align the dispersed nanofillers in one direction. After the alignment of nanofillers, we are planning to prepare nanofiller-aligned buckypapers by removing the LC polymers using a membrane with small pores.

In this study, in order to prepare CNF-aligned buckypapers, CNFs were dispersed in a nematic LC polymer and the possibility for aligning the CNFs was examined. The dispersion and changes in the alignment of CNFs were observed using an optical microscopy.

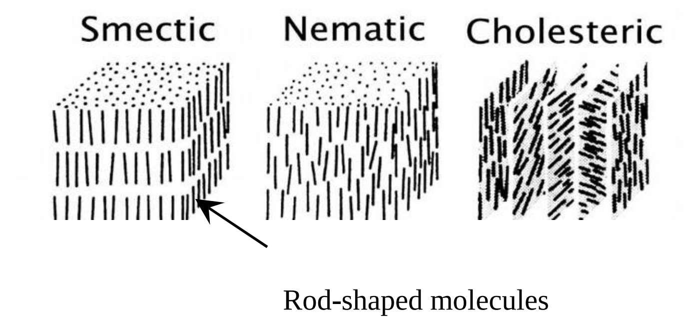


Fig.1 Alignment of LC molecules.

2. Experimental Procedure

The CNF used in this study was commercially available vapor-grown carbon nanofiber (VGCF) supplied by Showa Denko K.K, Japan. Observations by a scanning electron microscopy revealed that the VGCFs have an averaged diameter of ≈200 nm and fiber length of 10 - 20 μm as shown in Fig.2. The nematic LC polymer used was 4'-pentyl-4-cyanobiphenyl (5CB). The CNF-5CB mixture was prepared as follows. First, tetrahydrofuran (THF) solution with 0.0025 wt% CNFs was sonicated for 30 min. to promote dispersion. Then, 20 μ*l* of the CNF-THF mixture was added to 1 g of 5CB nematic LC followed by sonication for 1 min.

The test setups used for the alignment experiments of the CNFs are shown in Fig.3 and Fig.4. In the first experiment, the CNF-5CB mixture was dropped on a glass plate coated with transparent indium tin oxide (ITO) electrodes. Then, 20V DC electric filed was applied to the droplet to align the LC molecules. The rotation and movement of the dispersed CNFs associated with the alignment of the nematic LC molecules were observed by using an optical microscopy.

The second test setup is shown in Fig.5. The CNF-5CB mixture was filled into a sandwich cell with a ≈50 μm gap by capillary action as shown in Fig.5. Due to relatively small gap, there was a size selection with very large aggregated CNFs being prevented from entering the sandwich cell. Then, 20V DC electric filed was applied to promote the CNF alignment.

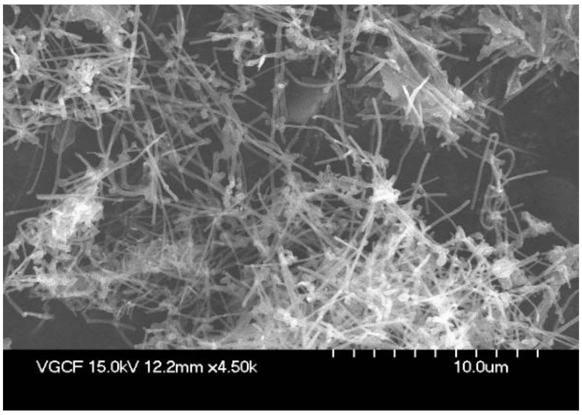


Fig.2 SEM image of VGCFs used in this study.

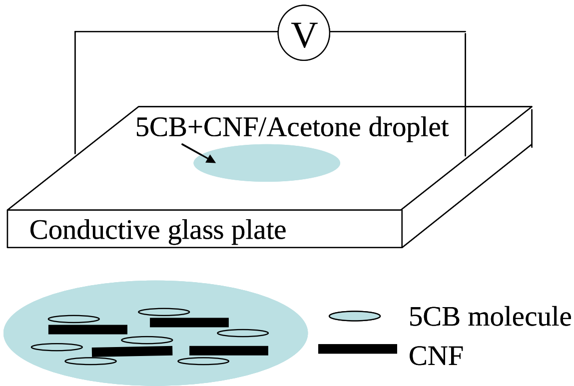


Fig.3 Test setup used for aligning the CNFs (droplet method).

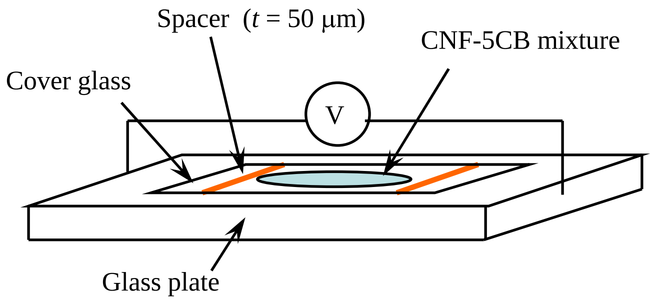
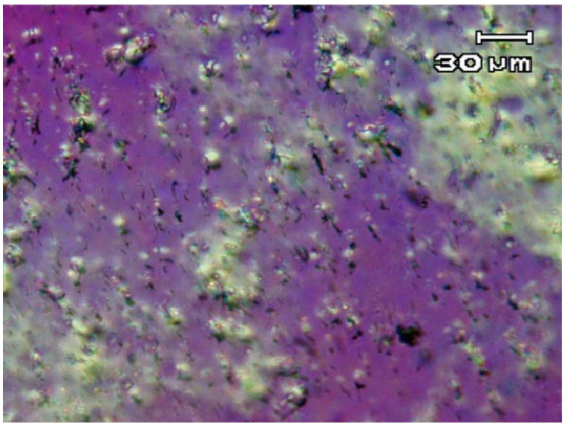


Fig.4 Test setup used for aligning the CNFs (sandwich cell method).

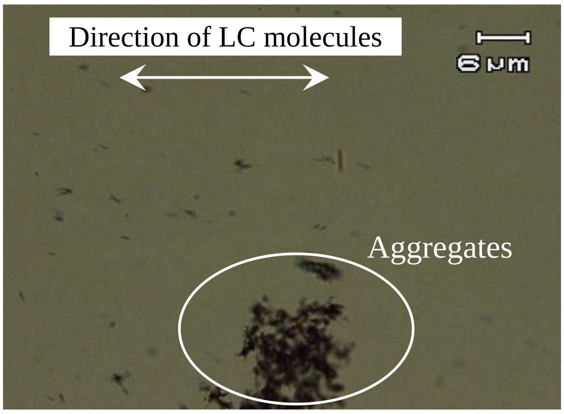
3. Results and Discussion

Figure 5(a) shows the typical optical microscopy image of the CNF-5CB mixture before applying electric field. Note that this image was taken for the droplet method. Although aggregates of CNFs were found, some individually-dispersed CNFs were also observed in the mixture.

After applying 20V DC electric filed to the CNF-5CB droplet, the color of the 5CB LC changed and a unidirectional flow occurred parallel to the applied electric field. The color change and unidirectional flow were caused by the unidirectional alignment of the long rod-shaped molecules of the 5CB LC. Simultaneously, individually-dispersed CNFs were observed to rotate and align parallel to the orientation of the LC molecules. Hence, it was confirmed that the phase change of the 5CB LC induced a driving force to align the CNFs. However, collision occurred between CNFs due to the convection flow in the droplet. As a result, large aggregates were gradually formed with time as shown Fig.5(b).



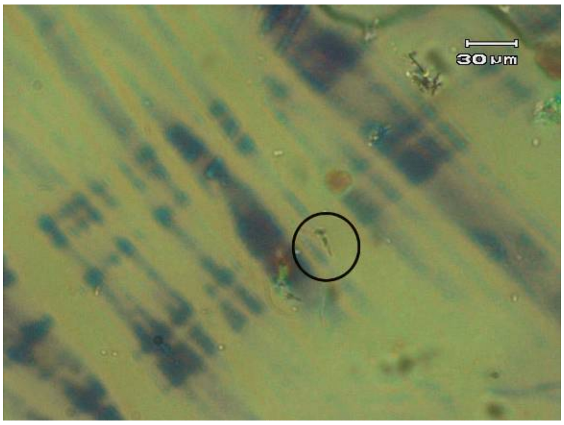
(a) Before applying electric field



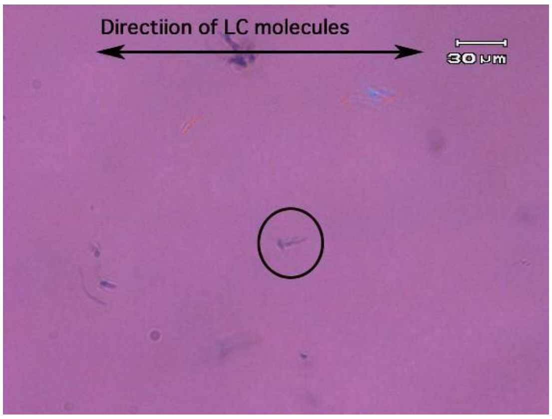
(b) After applying electric field

Fig.5 Optical microscope images of the CNFs dispersed in the 5CB nematic LC before and after applying 20V DC electric field (droplet method).

In the droplet method, unidirectional alignment of the CNFs was not achieved due to the formation of the CNF aggregates. Hence, in order to prevent the convection flow in the CNF-5CB mixture, a sandwich sell with a small gap (≈50 μm) was used in the second experiment. Figures 6(a) and (b) show the CNFs dispersed in the sandwich cell before and after applying 20V DC electric field. As shown in these figures, by applying the electric field, the CNFs rotated and aligned parallel to the 5CB LC molecules. However, technical difficulties still remain to prepare CNF-aligned buckypapers. For example, the density of the CNFs in this study is too small to prepare the buckpapers. In addition, the aggregation of the CNFs is expected to occur as the CNF density is increased. Further experiments are therefore required.



(a) Before applying electric field



(b) After applying electric field

Fig.6 Optical microscope images of the CNFs dispersed in the 5CB nematic LC before and after applying 20V DC electric field (sandwich cell method).

4. Concluding Remarks

In order to prepare CNF-aligned buckypapers, CNFs were dispersed in a nematic 5CB LC polymer and the possibility of aligning the CNFs in one direction was examined. In the droplet method, by applying electric fields, individually-dispersed CNFs were observed to rotate and align parallel the LC molecules. However, due to the convection in the droplet, collision between CNFs occurred and large aggregates were formed. In order to reduce the convection, CNF-5CB mixture was filled into a thin sandwich cell in the second experiment. In this case, the CNFs aligned parallel to the nematic LC molecules by applying electric fields. In addition, the formation of the CNF aggregates was prevented due to the reduced convection. However, further experiments are required to obtain CNF-aligned buckypapers because the examined density of the CNFs in the 5CB LC polymer is quite low.

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