Study of Ultrasonically Processed Polymer-Nanoparticle Solutions for Electrospinning

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Fall/2016

Biography

I completed my Bachelor's Degree in Mechanical Engineering at Georgia Southern University in May 2016. As an undergraduate student, I joined the Nanomaterials Research Lab at Georgia Southern University. My focus was on the fabrication and characterization of polymer nanocomposite fibers. More specifically, my research involved the production of ultra-high molecular weight polyethylene nanocomposite fibers containing surface modified carbon nanotubes. I am a member of the Society of Woman Engineers and the Society for Manufacturing Engineers. My main research interests are related to the development of manufacturing processes for high-performance lightweight materials.

Overview

Electrospinning is a process for fabricating polymer nanofibers from a polymer solution using an electrostatic field. The effectiveness of this process in producing nanofibers with a desired morphology and properties is dependent upon the appropriate combination of the process parameters and the characteristics of the polymer solution. There has been increasing interest in using electrospinning process for fabrication of polymer-based nanocomposite nanofibers with enhanced mechanical and physical properties along with tailored morphologies. Although there have been several methods developed for mixing nanoparticles in various polymer solutions for the electrospinning process, it is difficult to use a large volume of nanoparticles mixed in higher concentration of polymer solutions for the electrospinning process. In this work, different volumes of silicon carbide (SiC) nanoparticles were mixed in aqueous polyethylene oxide (PEO) solutions with different concentrations through the ultrasonic processing, and SiC nanocomposite PEO nanofibers were fabricated using electrospinning. Computational modelling was used to determine the appropriate geometrical parameters of the ultrasonic processing cell to obtain the largest cavitation zone size for a given volume of the solution. The morphology of the electrospun SiC nanocomposite PEO nanofibers were studied using scanning electron microscopy (SEM).

Motivation

The effectiveness of the electrospinning process in producing nanocomposite nanofibers with a desired morphology and properties is highly dependent on the characteristics of the polymer solution along with the dispersion and distribution of nanoparticles within the solution. High surface energy of nanoparticles acts as a barrier for their uniform dispersion and distribution in the solution, which can be overcome by using the ultrasonic cavitation and acoustic streaming effects of the ultrasonic processing. However, the conventional approach for selecting parameters for effective ultrasonic processing is largely based on trial and error. Therefore, a systematic methodology for selection of the ultrasonic processing parameters is thereby desired. There is limited scientific knowledge available regarding the use of polymer-nanoparticle solutions prepared by ultrasonic processing for electrospinning. We would like to investigate the effects of ultrasonic processing on the electrospinnability of the polymer-nanoparticle solution and also its influence on the resultant morphology of produced nanocomposite nanofibers.

State of the Art

Nanocomposite nanofibers are polymer nanofibers containing nanomaterials as a secondary phase of reinforcement and have shown to improve the tensile strength of polymer nanofibers. The reinforcement phases include silicates, carbon nanotubes and clay [1]. The conventional mode of solution processing for electrospinning involves a two-step process combining ultrasonic processing of nanoparticles within a solvent, followed by mechanical mixing of the polymer to form the final solution [2]. However, the drawback of this method is that the dispersion of nanoparticles can be disturbed by the secondary mixing step. Previous work on the ultrasonic processing of polymer solutions has shown that high molecular weight polymer chains were degraded to smaller sizes, which was dependent upon the exposure to ultrasonic energy [3]. Recently, several researchers have investigated ultrasonic processing of polymer-nanotube solutions as a viable and effective route towards physical functionalization of carbon nanotubes, and there have been some studies regarding electrospinning of sonicated polymer-nanoparticle solutions [4]. However, a systematic study of the electrospinnability and morphological development correlated with sonication parameters and nanoparticle contents has not been extensively studied.

Intellectual Merit

Our work would provide an in-depth understanding of the effects of ultrasonic processing of polymer-nanoparticle solutions for use in electrospinning. It will also establish a baseline of knowledge regarding the relationship of nanoparticle dispersion and distribution on the resultant morphology of nanofibers. This will inspire deeper research into materials processing-structure-property relationships of such electrospun nanocomposite nanofibers.

Broader Impact

The research outlined in this work will enable further development of the electrospinning process for scale-up manufacturing of nanocomposite nanofibers with custom morphologies and controlled distribution of nanoparticles. Such developments will pave the way towards future novel applications of high-performance lightweight materials with enhanced mechanical and physical properties.

Research Approach

A computational modelling was used to determine the appropriate geometric configuration of the ultrasonic processing cell for a constant volume (50 mL) of solution. For experimental validation of the results from the computational modeling, SiC nanoparticles were sonicated in DI water for the sedimentation test. The level of sedimentation in the solution was observed and compared during 72 hours after the ultrasonic process was completed. SiC nanoparticles with different contents were sonicated in aqueous PEO solutions with varying concentrations. Another set of solutions was also prepared using mechanical stirring to compare mixing effectiveness against the sonicated solution. The viscosity and surface tension of the precursor solutions were then measured. Each solution was then loaded into a custom electrospinning setup for nanocomposite nanofiber fabrication. The morphology of the electrospun nanocomposite nanofibers was observed using SEM. Tensile test will be carried out using electrospun nanocomposite nanofiber membrane, and hardness will be measured with nanoindentation. Chemical and thermal properties will also be investigated.

Findings to Date

Using the computational modelling, the largest cavitation zone size was determined for various ranges of three dimensionless geometrical parameters related to the probe diameter, such as the position of the probe inside the liquid, the size of the ultrasonic processing cell, and the volume of the solution. SiC nanoparticles with a diameter of 50 nm were ultrasonically processed in three different cases, and it was observed that the nanoparticles sonicated using the appropriate geometric configuration resulted in reduced sedimentation for 72 hours of observation, compared to the others. In addition, the viscosity and surface tension of the sonicated solutions were significantly lower than that of the mechanically stirred solutions. SEM images of nanofibers electrospun from the sonicated PEO-SiC solutions showed that there was a formation of beads and discontinuous nanocomposite nanofibers, which was different from the case using ultrasonicated PEO solutions of the same concentration without nanoparticles. It was also found that there was an increase in bead frequency throughout the fiber length with the addition of SiC nanoparticles. There was less formation of the beads or discontinuous nanocomposite nanofibers when the mechanically stirred solution with the same material content was used.

Conclusions

These findings indicate that although better dispersion of nanoparticles can be achieved with ultrasonic processing, the rheological properties of the polymer solution related to its electrospinnability are significantly affected. Therefore, it is evident that the electrospinning parameters required to achieve obtain better control of the electrospinnability of sonicated polymer solutions will be significantly different from that of conventionally mixed solutions. However, it was observed that formation of nanofibers is possible from sonicated polymer solutions containing nanoparticles. Future investigations related to this work will be based on determination of the effects of nanoparticle dispersion on the rheological behavior and electrospinnability of the solution. The morphological development, mechanical and physical properties of the nanocomposite nanofibers will also be further investigated.

References

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