Abstract

Recent studies on piezoelectric materials have resulted in the development of a wide verity of piezoelectric devices such as nanogenerators and sensors. This technology is dominated by the ceramic materials which are brittle and have a very limited strain level. Moreover, despite a wide working frequency range of ceramic materials, the ceramic-based piezoelectric devices work only under tiny forces to avoid damage to the device. The piezoelectric technology has not been widely explored in civil engineering applications due to the aforementioned drawbacks of ceramic materials. This thesis aims to develop an efficient piezoelectric polyvinylidene fluoride (PVDF) nanofiber device which can be used in both energy harvesting and sensing civil infrastructure applications. The β-phase of PVDF is responsible for its electroactive properties such as ferroelectric, piezoelectric and pyroelectric properties. In spite of several efforts to improve the β-phase content, it is still a challenge to fabricate a PVDF sensor with high efficiency due to the complication of the required post-treatment process which mainly includes electrical poling and mechanical stretching. The electrospinning method was used in this study to synthesize the cost-effective and large-scale piezoelectric nanofiber composite, making it considerably more attractive for commercial industrial and civil engineering applications. The process-structure-property relations of electrospun PVDF nanofiber has been systematically studied. As a result, a reliable model was developed that enables an accurate prediction of PVDF structure properties, particularly morphological and a fraction of the β-phase content. It was found that the fraction of β-phase is considerably affected by evaporation rate so that the high concentration of PVDF and DMF/acetone decreases the evaporation rate of the solution resulting in a formation of a high fraction β-phase content. The electrospinning method was found to be very effective to promote the β-phase formation in PVDF nanofiber. In fact, electrospun PVDF nanofibers were experienced high electrical field and mechanical stretching during the fabrication which eliminates a need for the post-treatment process. This study proposes a core-shell structured PVDF-graphene oxide (GO)

nanofiber composite, in which the polar phase content and piezoelectric properties are considerably improved. The results indicate that only 0.2 wt. % of GO is enough to nucleate most of the PVDF polymer chain. It was found that the β-phase content in core-shell structured PVDF-GO nanofiber composite can reach up to 92 % for which is 23% and 73 % higher than the neat electrospun PVDF and spin coated PVDF, respectively. This suggests that the core-shell structure of PVDF-GO is effective in improving the phase transformation of α-phase to β-phase, even at a low content of GO. As an interior core-shell, the GO is solidified into nanofiber form which increases the number of heterogeneous nucleation sites to interact with the PVDF polymer chain. The d_{33} piezoelectric coefficient of PVDF-GO was found to be 61 pm/V which is almost two times higher than PVDF nanofiber. The enhancement of the piezoelectric coefficient can be attributed to the higher β-phase content which can induce a stronger displacement in the sample as a result of the applied electrical field. This might be because of the interaction between the π-bond in GO with the fluorine atoms and hydrogen atoms on adjacent carbon atoms in PVDF polymer chains. The alignment of atoms at two sides of the polymer chain not only induces the beta phase formation but also results in a formation of a net polarized dipole moment along the core-shell structure of PVDG-GO nanofiber. The feasibility of using PVDF device for energy harvesting and sensing applications was assessed by conducting a series of experiments. According to the results, the optimized frequency range for the device was found to be 45 Hz. The results indicated that the voltage output starts to decay at a higher frequency which can be due to the insufficient time for the PVDF nanofiber to be recovered from the induced strain. The variation of the amplitude has a great influence on the voltage output of the piezoelectric device. The voltage output of the PVDF device is enhanced with increasing the amplitude due to the higher amount of induced strain. In fact, the amount of induced strain can be considered as the main source of the available mechanical energy which can be fed into the piezoelectric device to be converted to the electrical energy. The results clearly show that both frequency and amplitude can affect the voltage output of the piezoelectric device. The highest obtained

voltage output can be obtained at the frequency range between 30-45 Hz. The sensing ability of the PVDF device was assessed in both active and passive situations. A pitch-catch system was set up in the lab to assess the efficiency of the flexible PVDF device for active sensing application. A series of experiments were conducted to evaluate the effect of several parameters of the transmitted signal such as amplitude and frequency on the received signal. The effect of transducer-sensor distance was also considered to evaluate the attenuation of the transmitted signal. The PVDF sensor was found to be effective in detecting the pulsed and continuous generated Lamb wave. It was found that the efficiency of the PVDF sensor in detecting the signal is not sensitive to the amplitude of the transmitted signal. Also, the transmitted signal's amplitude has an insignificant effect on the attenuation rate of the transmitted signal over the distance. It means that the efficiency of the PVDF sensor in detecting the Lamb wave signal is not affected by the amplitude of the transmitted signal. However, the efficiency of the PVDF sensor to detect the transmitted signal is highly affected by the distance between the transducer and receiver. The results indicate that the PVDF device is less efficient in detecting the transmitted signal either at a low-frequency range (<1 kHz) or the higher range of frequency (> 100 kHz). The optimized frequency was found to be in the range of 1 kHz to 100 kHz to enhance the efficiency of the PVDF sensor. The efficiency of PVDF sensor for detecting the acoustic wave was also studied by hammer impact testing. These results clearly indicate that the sensor is able to detect different magnitudes of surface acoustic waves propagating on the surface. The higher of the impact energy applied to the concrete, the higher the voltage generated by electrospun PVDF AE sensor. The results of this thesis can assist in adopting the electrospun PVDF piezoelectric sensor in a variety of sensing and energy harvesting applications in civil engineering infrastructure.