ARC '16

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http://dx.doi.org/10.5339/qfarc.2016.EEPP2566

Mechanical Behavior of a Novel Nanocomposite Polysulphone – Carbon Nanotubes Membrane for Water Treatment

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Nowadays, global fresh water shortage is becoming the most serious problem affecting the economic and social development. Water treatment including seawater desalination and wastewater treatment is the main technology for producing fresh water. Membrane technology is favored over other approaches for water treatment due to its promising high efficiency, ease of operation, chemicals free, energy and space saving. Membrane filtration for water treatment has increased significantly in the past few decades with the enhanced membrane quality and decreased membrane costs. In addition to high permeate flux and high contaminant rejection, membranes for water treatment require good mechanical durability and good chemical and fouling resistances. Thus, investigation of the mechanical behavior of water treatment membranes with underlying deformation mechanisms is critical not only for membrane structure design but also for their reliability and lifetime prediction.

Compared to ceramic and metallic membranes, polymer membranes with smaller pore size and higher efficiency for particle removal are widely used in seawater desalination with a high applied pressure. However, polymer membranes are mechanically weaker and have lower thermal and chemical stability compared to inorganic membranes. Blending of polymers with inorganic fillers is an effective method to introduce advanced properties to polymer based membranes to meet the requirements of many practical applications. The reinforced polymeric membranes with inorganic fillers can provide desirable mechanical strength as well as mechanical stability. Carbon nanotubes (CNTs) have received considerable attention from academic and industries over the last twenty years. In addition to their excellent electrical and thermal properties, CNTs exhibit outstanding mechanical characteristics due to its instinct mechanical strength and high aspect ratio. For the application of water treatment membranes, CNTs could be the excellent channels for water to go through and therefore, CNTs have proven to be excellent fillers in polymer membranes improving the permeability and rejection properties. In literature, it is reported that the

Cite this article as: Wang K, Manawi YM, Kochkodan V, Hussien MA, Khraisheh MK, Benamor A. (2016). Mechanical Behavior of a Novel Nanocomposite Polysulphone – Carbon Nanotubes Membrane for Water Treatment. Qatar Foundation Annual Research Conference Proceedings 2016: EEPP2566 http://dx.doi.org/10.5339/qfarc.2016.EEPP2566.

mechanical strength of the polymer membranes was improved with the embedding of CNTs due to reinforcement effect of the more rigid CNTs. The mechanical responses of polymer_CNTs composites depended on the interfacial adhesion between the CNTs and the membrane-based polymer as well as the dispersion and distribution of the CNTs within the polymer matrix.

In this study, a vertical chemical vapor deposition reactor was designed in order to synthesize CNTs of high aspect ratio using continues injection atomization. Bundles of high purity (99%) and high quality CNTs were produced by this system. The produced CNTs had diameters ranging from 20 to 50 nm and lengths ranging from 300 to 500 micron (corresponded aspect ratios ranging from 6000 to 25000). A novel polysulphone (PSF) based nanocomposite membrane incorporated with the produced high aspect ratio CNTs was then casted via phase inversion method, at a wide range of CNTs loading (0–5 wt. %), in polysulphone-dimethylformamide solutions using the Philos casting system. The poly(vinylpyrrolidone) was used as pore-forming additive. To demonstrate the effect of nanocomposite morphology on the mechanical behavior of the prepared membranes, a set of control samples consisted of PSF membranes embedded with commercial CNTs at the same CNTs loading, were casted at the same conditions. The commercial CNTs had a lengths of 1 µm to 10 µm and outer diameters of 10 nm to 20 nm (corresponded aspect ratios ranging from 50 to 1000), with purity >95% and BET surface area of 156 m^2/g.

The effects of CNTs content and aspect ratio on morphological, water transport and mechanical properties of the prepared PSF-based porous membranes were investigated. The surface and cross-section morphologies of PSF/CNTs porous membranes were examined using scanning electron microscopy (SEM). The orientation, dispersion and distribution of CNTs within polymer membranes were evaluated for the membrane samples with different CNTs content and CNTs aspect ratio. The average membrane pore size was evaluated by using SEM image analysis software.

Uniaxial tensile behavior of the membranes was characterized by means of a universal material testing machine under different testing conditions. Wet specimens were carefully cut from the casted membranes by using a razor blade. Elastic, plastic and failure behaviors of the membranes are analyzed with the impacts of CNTs content and aspect ratio. The macroscopic mechanical behaviors of the membranes are correlated with their strain induced microstructure evolution by using SEM. In this, pore shape evolution, pore and CNTs orientations, neighboring pore interaction, interface between the CNTs and PSF matrix and the failure behavior of the deformed porous membranes were analyzed. The macroscopic stress-strain responses of the membranes were correlated with the microstructure of the studied nanocomposites membranes to provide a better understanding of materials' processing-microstructure-properties relationship.