

Full Length Research Paper

Porous and non-porous electrospun fibres from discarded expanded polystyrene

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In this study, we report the electrospinning of expanded polystyrene (E-PS) in xylene and tetrahydrofuran to produce microfibrils. The aim is to develop a viable technique for waste polystyrene electrospun fibers for various applications. The E-PS was dissolved in xylene and tetrahydrofuran (THF), spun at voltage range of 10 to 28 kV keeping the spinning distance constant. The E-PS was characterized with Fourier transform infra red spectrophotometer (FTIR) and fibres obtained were characterized by scanning electron microscopy (SEM). The diameter of the fibres formed is in the range of 1.0 to 25.0 μm . The results obtained clearly justify the use of discarded E-PS as an inexpensive substitute for the specialized polymer carriers commonly used in electrospinning work.

Key words: Electrospinning, fibre, expanded polystyrene.

INTRODUCTION

Electrospinning (also known as electrostatic spinning) is a technique which involves the application of a high voltage (in the order of 5 to 50 kV) to a polymer solution in which charges are induced and eventually fibres are produced. A typical electrospinning facility comprises a feed reservoir – nozzle assembly and an earthed conductive collector (target) of lower potential which attracts the jet that is formed (Figure 1). Electrospinning occurs when the applied electrical force exceeds surface tension of the polymer solution at the tip of the nozzle (Reneker and Yarin 2008). The polymer concentration is increased due to solvent evaporation on the surface of the jet. Polymer solutions such as polyethylene oxide (PEO), polystyrene (PS) etc in volatile organic solvents such as n-hexane, toluene, xylene, tetrahydrofuran (THF) or diethyl ether are commonly used. Some of the parameters that affect electrospinning are the polymer solution itself, operating conditions (such as the applied

voltage, separating distance of the nozzle and the collector (spinning distance), nature of the collector and ambient conditions (temperature, pressure and humidity) (Fujihara et al., 2005).

Polystyrene, with IUPAC name poly(1-phenylethene-1,2-diyl) is an aromatic polymer made from the aromatic monomer styrene, a liquid hydrocarbon usually produced commercially using petroleum derivatives (Figure 2). PS is a thermoplastic material, solid at room temperature and can be extruded if heated above its glass transition temperature and becomes solid again when cooled.

Solid PS is used for plastic models (assembly kits), disposable cutlery etc. Products made from expanded PS are used in packaging materials, insulation etc. E-PS is a rigid and tough closed-cell foam, usually white in colour (Neil, 2009). Foamed/expanded polystyrene is known to be resistant to biodegradation and photolysis. PS foam is a major component of plastic debris in water bodies which become toxic to marine life. Weathering by wind, sun, rain and wave action however, degrade PS to known and suspected carcinogenic including styrene monomer, styrene dimer etc. Hydrochlorofluorocarbon (HCFC) which is a blowing agent for extruded PS has been reported to

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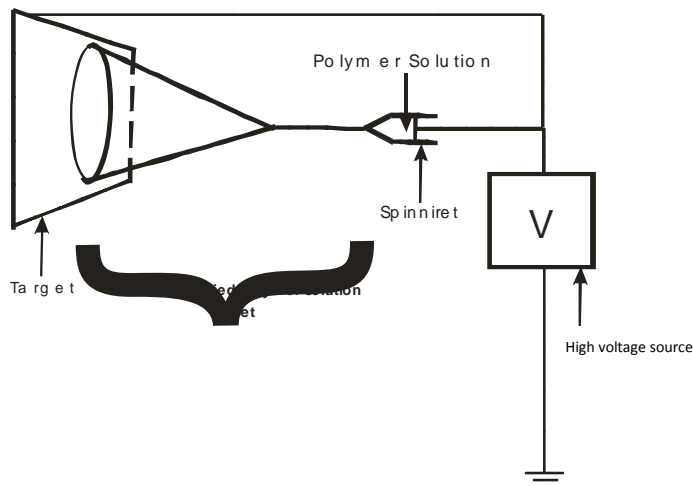


Figure 1. A typical electrospinning set-up.

have ozone depletion properties. Their ozone depletion potential is comparatively lower than that of chlorofluorocarbons (CFCs) which were formerly used but their global warming potential is in the order of 1000 when compared with CO_2 (ICPC, 2001). Thus, the need to find more environmental friendly applications for waste expanded PS is of great importance. Polystyrene has been used as a model polymer to focus on, owing to its transparency and broad solubility in organic solvents. Previous efforts by numerous scientists revealed that morphology of electrospun polystyrene fibre in various solvents is dependent on the boiling point and the dipole moment value of the solvent used (Chin and Jin, 2005; Demir, 2010). A non-woven fibre material of polystyrene had been achieved by electrospinning which offers numerous existing and potential applications in filtration, catalysis, textile covering and tissue engineering (Demir, 2010).

There exists several methods for producing fibres such as deposition methods (as in this case), ball milling technique (Corrias et al., 1997), synthesis in reverse micelles (Lisiecki and Pileni 1993), Langmuir-Blodgett film (Jin et al., 1998), and self-assembled and monolayers (Gedanken et al., 1999). In this work, expanded polystyrene (E-PS) was the polymer used for the production of fibres with the aim of investigating the potential of fibre production from these discard polystyrene which litters the environment and identify the potential applications of the fibres.

EXPERIMENTALS

Materials and equipment

Discarded expanded polystyrene (E-PS) blocks used in this work were the packaging foam blocks normally found in the cartons of

newly purchased electronic products, a small pieces was characterize with Fourier transform infra red spectrophotometer (FT-IR). Xylene and tetra hydrofuran (THF) (BDH Chemicals, UK) was used as the solvent. The high voltage source used in the experiment was assembled by the Materials Science and Electronics Division of the Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife with an accuracy of ± 0.25 kV.

Procedure

4.0 g of expanded PS pieces was dissolved in 10 ml of xylene and THF. Mixing was done at 30°C for 4 h using a hotplate with magnetic stirrer to ensure even dispersion of the PS pieces. The solution was fed into electrospinning unit which comprised a high voltage source (0 to 40 kV), feed reservoir and nozzle assembly, and an earthed collector. Aluminium foil was used as the collector in this case. The onset potential difference was between 15 to 20 kV in both solvents. The distance between the tip of the nozzle and the collector was maintained at 20 cm while the applied voltage was varied between 22 and 28 kV. After 30 min, the collectors were removed, dried in a stream of dry nitrogen gas at 30°C and kept in airtight containers. The fibres formed on the collectors were imaged by scanning electron microscopy (SEM) and fibre size was determined using ImageJ software.

RESULTS AND DISCUSSION

Figure 2 shows in-phase, out-phase, wagging vibrations of adjacent hydrogen of substituted benzenes giving rise to strong adsorption in well defined frequency range of 906 to 696 cm^{-1} . Absorption band at 696 and 754 cm^{-1} were as a result of mono substituted benzenes and the five hydrogen atoms gave rise to the two absorption bands. 1600 to 1452 cm^{-1} was as a result of in-plane skeletal vibrations of the aromatic rings which involve expansion and contraction of carbon-carbon within the ring; 2920 to 2848 cm^{-1} denotes C-H (alkyl group) symmetric and asymmetric vibration. 3026 cm^{-1} indicates C-H stretching vibrations in the aromatic ring and 3061 cm^{-1} indicates that aromatic C-H bonds also show weak absorption. The diameters of the fibres formed are in the range of 1.0 to $15.0\text{ }\mu\text{m}$. The large average diameter obtained was due to reduced elongation of the fibres, caused by high concentration as a result of volatile nature of the solvent (Christodoulides and Hadjipanayis 1997; Demir, 2010) which consequently led to high viscosity of the slurry. Clusters of fibres were observed in Figure 3a, b2 and c and increases as the applied voltage decreases. The highest degree of cluster was obtained at 22 kV (Figure 3a). Inconsistent beads were observed in Figure 3d1 which could be as a result of fairly high viscosity of the polymer mix. That accounts for gradual diminishing of beads forming a more spindle like structure. The fibres formed are thus better described as continuous and bead-free thick fibres. The voltage range of 22 to 28 kV revealed that higher voltage gave finer fibers as observed in Figure 3 (b1 and d1). This observation agrees with established knowledge that low concentration and viscosity

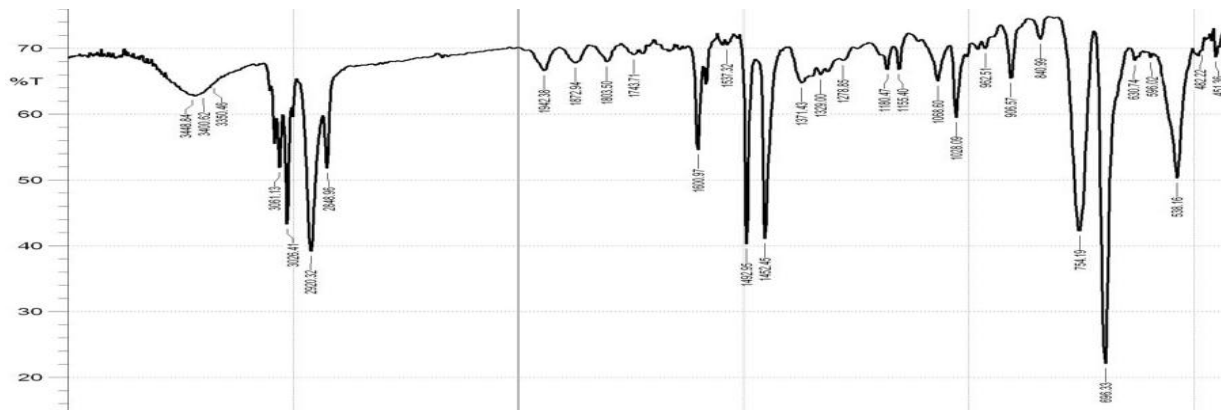


Figure 2. FT-IR spectra of E-PS.

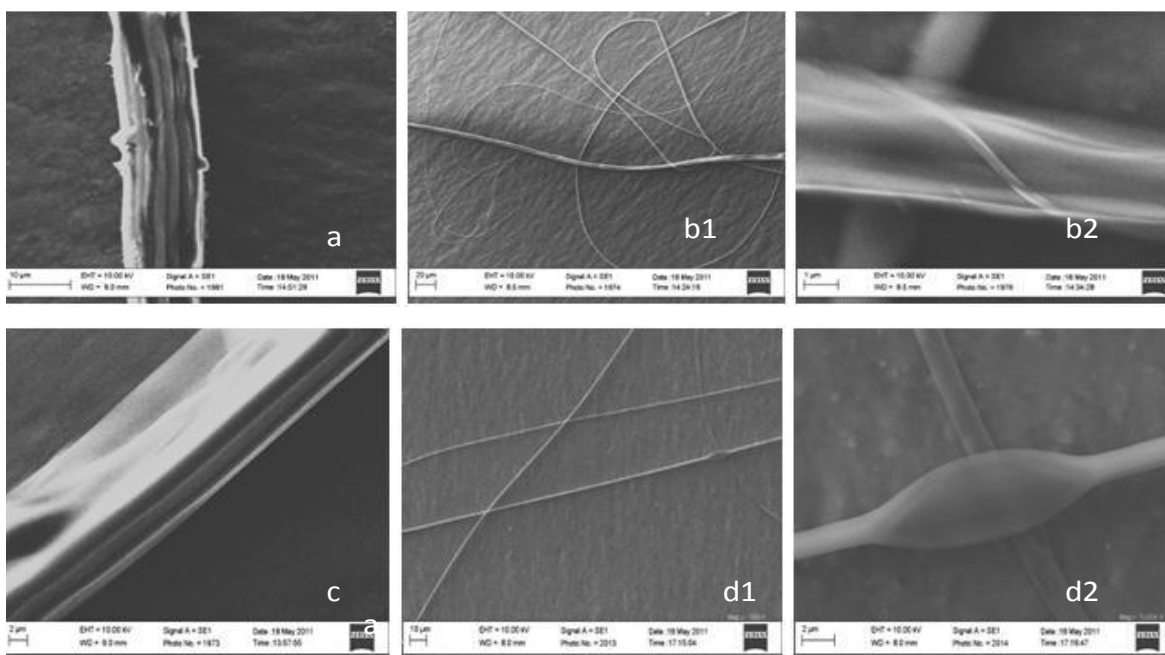


Figure 3. SEM micrographs of E-PS in xylene.

yields higher bead formation (Christodoulides and Hadjipanayis, 1997). Formation of non-porous fibres can be attributed to control polymer concentration in volatile solvents due to lower evaporation rate of xylene (Alayande et al., 2011). Comparison of the solvent effect with the use of highly volatile solvents like DMF, THF or co-solvents of both led to uncontrollable polymer concentration reported by Chin and Jin (2005). This is observed in Figure 3d2 where the applied voltage is 28 kV. The bead formation can be attributed to high electrostatic force that attracts the polymer jet to the conductive collector. The average diameter of the beads formed is about $4.02 \mu\text{m}$ while the fibres gave $1.61 \mu\text{m}$. Figure 3d2 whose applied voltage is 28 kV. The diameter and bead concentration of the fibre are dependent

significantly on concentration, applied voltage, spinning distance and viscosity of the polymer mix. Non-formation of pores on the fibre was as a result higher boiling point of the solvent used (Demir, 2010).

Figure 4 shows cross section of polystyrene fibers electrospun from THF solution. A thin uniform skin surrounding a homogeneously porous core is evident. Even though the fiber core remains robust, the skin of fiber is fractured down as indicated with a white arrow. This observation suggests the brittle and glassy nature of the skin. Figure 4e to j presents higher magnified image of a representative fiber. Two types of pores here can be identified: (i) The interior porosity, and (ii) The surface porosity. Based on the SEM images, the interior porosity appears to be stronger in Figure 4 i and j than the surface

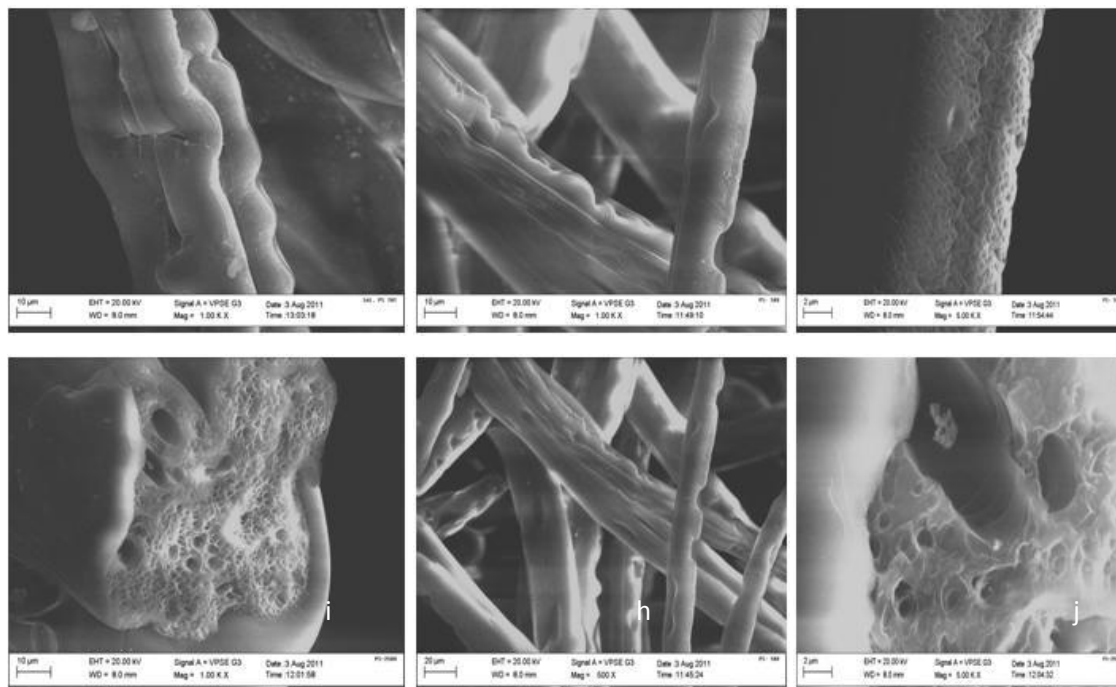


Figure 4. SEM micrographs of E-PS in THF.

porosity in Figure 4e to g. Therefore, the contribution of former porosity to the surface area of entire system is expected to be much higher than that of the latter one. Although electrospinning process is very fast and polymer molecules are far from equilibrium, this porous morphology may be a consequence of phase separation occurring between moisture in air and THF. This phenomenon is very well-known and widely discussed in literature. There are two relevant phase separation mechanisms in the course of fiber evolution: Thermally induced phase separation and vapor-induced phase separation (Demir, 2010). The former is associated with the rapid solvent evaporation that lowers the local temperature on the liquid jet although the temperature of spinning environment is unchanged. The cooling due to evaporation will result to condensation of moisture in air and the formation of breath figures; therefore, pores occur only on the surface of the fibers. The latter is ascribed to the presence of water vapor in the surrounding air which acts as non-solvent. The polymer solution undergoes phase separation by diffusion of water vapor. The pore formation is governed by polymer fraction. Increasing fraction of polymer increases the internal pore formation, which is consistent with our results. Both interior and surface porosity of the electrospun E-PS fibers were porous; we can conclude that both phase separation mechanisms coexist in formation of the fibers using THF. Vapor induced phase separation appears to have stronger contribution compared to thermally induced phase separation. These

phase separation resulted in the formation of nano and micro pores on both the interior and surface of the fibres.

Conclusion

The porous and non-porous fibres produced from E-PS waste were in micro-dimensions (1 to 25 μm). The porous micro fibres can be used as catalyst carrier, separation techniques and membrane while the non-porous fibres can be used as textile covering, insulator and sensors. Hence, E-PS which would otherwise, litter the environment can be re-engineered into valuable industrial products.

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