

Polystyrene

Erica Wilkes

Polystyrene is a polymer made from the synthetic aromatic monomer styrene. Styrene in turn comes from the catalytic dehydrogenation of ethylbenzene. Although ethylbenzene is found naturally in petroleum, the majority of it is produced by combining benzene, a component of crude oil, and ethylene, a natural plant hormone that is also produced by steam cracking gaseous or light liquid hydrocarbons by the petrochemical industry, in a chemical reaction that is acid catalyzed (Wikipedia, 2014).

Polystyrene has the chemical formula $(C_8H_8)_n$. Its structure consists of a long chain hydrocarbon where the center carbons are bonded to benzene rings, or phenyl groups. Free radicals are used to initiate the polymerization of the styrene monomers by breaking the vinyl group's carbon-carbon pi (double) bond and creating a carbon-carbon sigma (single) bond, thus extending the chain with another styrene monomer. This method creates atactic polystyrene where phenyl groups are randomly placed on either side of the polymer, preventing crystallinity. It is the atactic polystyrene that is commercially produced. Syndiotactic polystyrene can be produced with the phenyl groups on alternating sides of the molecule through the Ziegler-Natta polymerization method. However, because polymerization is slow using this method, it is not used commercially. There is also an isotactic polystyrene, where all of the phenyl groups are on the same side. This is also not produced commercially (Wikipedia, 2014).

The structural formula of polystyrene and its polymerization is show below.

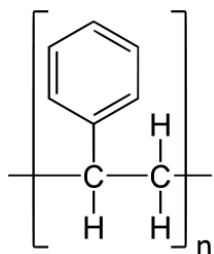


Fig.1 Structural formula of polystyrene (Wikipedia, 2014).

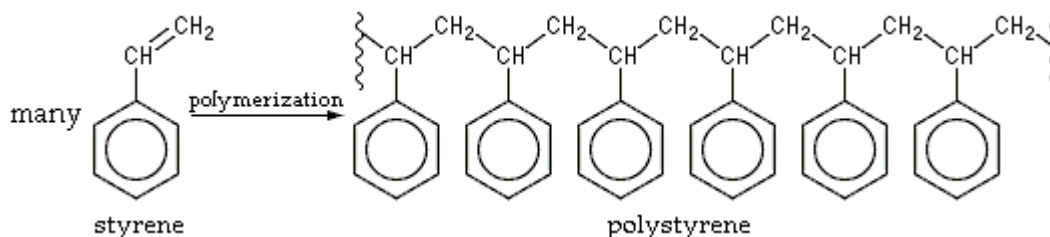


Fig.2 Polymerization of polystyrene (Wikipedia, 2014).

Polystyrene is used as a polymer in the process of electrospinning to create fibers that range in diameter from nanometers to a few microns. This is a simple, repeatable process that involves placing a polymer solution, or melt, into a syringe or cap to which an electric field is then applied. The applied electric potential overcomes the surface tension of the polymer solution. A polymer jet is then ejected from the syringe needle tip and is deposited onto the collector as a non-woven web. The repulsive electrostatic forces create bending instabilities that cause the jet to spiral as its traveling to the collector. To minimize the instability, the jet undergoes plastic stretching, which reduces its diameter, thus forming extremely thin fibers. If one uses a low polymer concentration, fibers may not form due to the jet breaking down into droplets as an electrospray instead. Changing the polymer concentration, and thus the viscosity, changes the diameter of the fiber and the number of beads that form on the fiber. An increase in viscosity has been shown to increase the fiber diameter. Viscosity is determined by both the concentration and molecular weight of the polymer (among other factors) (Shenoy *et al* 2005). The fact that polystyrene has a high molecular weight is important due to the fact that both concentration and molecular weight affect the number of polymer chain entanglements, which plays a huge role in fiber formation. The higher the molecular weight, the more chain entanglements. This affects the viscoelastic behavior of the polymer solution during electrospinning since the chain entanglements act similar to chemical cross links but allow the chains to slide past each other. Thus, there are sufficient forces to overcome capillary instability and hold the jet together, yet enough low enough strain rates to allow viscoelastic behavior and avoid fracture causing fiber breakage(Shenoy *et al* 2005). There are many other parameters that affect electrospinning and fiber formation, such as the properties of the polymer solution including solution conductivity, solution surface tension and solvent volatility (Shenoy *et al* 2005), as well as infusion rate, applied voltage, distance to the collector, motion of the collector, humidity and temperature (Kumbar *et al* 2008).





Fig. 4 Electrospinning equipment with fibers evident at the syringe tip.

Since polystyrene is not conductive, it must be dissolved in a conductive solvent, such as dimethylformamide (DMF), D'Limonene or Toluene, for electrospinning to take place. It will then be part of a polymer solution that would react to the electric field that is created. Solutions with low conductivity will create fibers that have many beads (Kumbar *et al* 2008). However, if one attempted to electrospin only the conductive solvent without the polystyrene, fibers would not be formed and the result would consist of electrospray instead.



Fig. 5 Polystyrene dissolving in D'Limonene

Nanofibers have a diameter of less than 1 μm and therefore have an extremely high surface area to mass ratio. Due to this property, and a variety of pore size, they have unique mechanical properties for chemical or physical surface functionalization. Other materials can be added to the original polymer solution to give the nanofibers particular properties for various applications such as tissue engineering, enzyme immobilization, ion exchanger and sensors (Uyar and Besenbacher 2008). In the Advanced Materials Bio and Integration Research (AMBIR) Laboratory at The University of South Florida, cactus mucilage is being added to the polystyrene solution to create nanofibers that can help filter heavy metals, such as arsenic, out of water. Since polystyrene is immiscible in water, it will not dissolve as it is filtering water. Colbalt doped antimony tin oxide (ATO) is being added to the polystyrene solution to create nanofibers targeted for thermal reflective military applications. These lightweight fibers can coat military devices and resist laser induced damage (Richard 2013).

The AMBIR lab is also striving to find nontoxic, environmentally friendly solvents to use for electrospinning and to include in their life-cycle assessments using the computer software SimaPro. In an effort to avoid using HAP (hazardous air pollutant) solvents, the AMBIR lab is using Formula 66 to replace toluene. Polystyrene did not originally dissolve in Formula 66 at room temperature. Since polystyrene is a thermoplastic polymer with a low melting point of about 240°C and a glass transition temperature of 100°C , we are able to dissolve it in formula 66 using heat. Polystyrene has a very high molecular weight with its polymer chains interacting through weak, intermolecular forces, or Van Der Waals forces, even though each hydrocarbon chain has high intramolecular strength. When heated, the chains are able to slide past each other, making the material flexible and elastic. Because of its thermoplasticity, polystyrene can also be extruded to create everyday items such as plastic utensils and DVD cases. Expanded polystyrene foam is used to make packing peanuts and extruded polystyrene foam is used to make Styrofoam (Wikipedia, 2014).



Fig. 6 Nanofiber mat

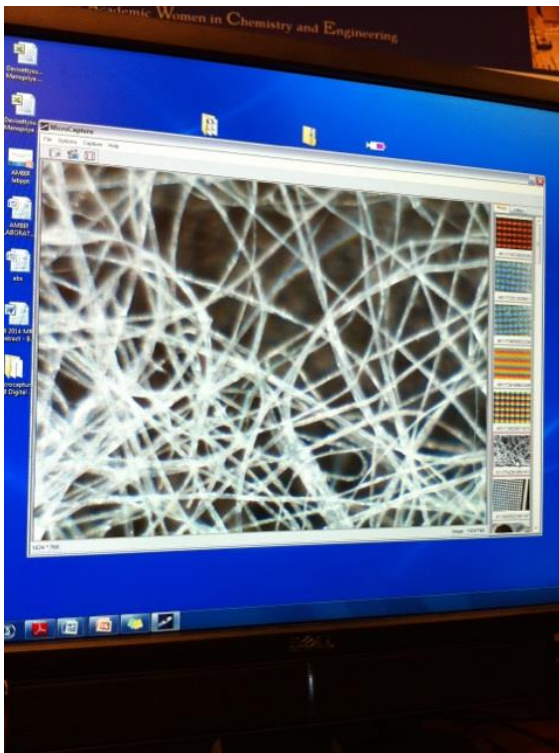


Fig.7 Nanofibers magnified 150x

References

Wikipedia.com The Wikimedia Foundation, Inc. Accessed 10 July 2014. (Polystyrene)

<http://www.wikipedia.org/>

Kumbar S. G., James R., Nukavarapu S. P., and Laurencin C. T. “Electrospun nanofiber scaffolds: engineering soft tissues” *Biomed. Mater.* (2008) Vol. 3, No. 034002.

Uyar Tamer and Besenbacher Flemming “Electrospinning of uniform polystyrene fibers: The effect of solvent conductivity” *Polymer* (2008) Vol. 49, No. 24, pp. 5336-5343.

Shenoy Suresh L., Bates W. Douglas, Frisch Harry L. and Wnek Gary E. “Role of chain entanglements on fiber formation during electrospinning of polymer solutions: good solvent, non-specific polymer-polymer interaction limit” *Polymer* (2005) Vol. 46 pp. 3372-3384

Richard, Brandon “Thermal Infrared Reflective Metal Oxide Sol-Gel Coatings for Carbon Fiber Reinforced Composite Structure”. PhD Dissertation. (2013) University of South Florida. Tampa, Fl.