Wood Waste Derived Anti-bacterial and Biodegradable Nano-fibers for Filtration Applications

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Wood Waste Problem in Hong Kong

Global warming intensifies tropical cyclones, accelerates the rise of sea level and has a profound impact on Hong Kong's environment. Especially, the super Typhoon Mangkhut in 2018 induced a maximum storm surge of 3.4 m and caused devastating damage to the Hong Kong environment, such as fallen trees and leaves. According to the Environmental Protection Department (EPD), a total of 44,600 tons of yard wastes was sent to landfill in 2018, in which 20,480 tons were tree wastes. These wastes were eventually ended up in a landfill in Tuen Mun, and only 900 pieces of wood were selected for reuse. The average daily quantities of wood/rattan wastes in 2021 was about 262 tons, mainly produced by the industrial and commercial activities. Apart from landfill saturation problem, these wastes produced greenhouse gas emissions of ~ 360 tonnes of CO_2e every day. These wood having lignocelluloses contain extended structures of cellobiose units (cellulose and hemicellulose) and polymeric lignin polymers, which can be further modified to give special functions such as anti-bacterial and electrostatic properties for effective capture and destruction of bacteria and viruses. These types of filter can be potentially applied in $PM_{2.5}$ treatment, in indoor air quality control and in preventing the spread of airborne diseases. Thus, this could be a "trash to treasure" opportunity to recycle wood wastes.

Microplastic Problem in Hong Kong

Meanwhile, with the increasing risk from $PM_{2.5}$ exposure and other contagious diseases, such as the recent outbreak of contagious COVID-19, the use of disposable face mask to stop the widespread of the infectious disease become ubiquitous around the globe. The material most commonly used to make face mask is polypropylene (PP) in the non-woven form, as this provides better bacteria filtration and air permeability while remaining less slippery than a woven cloth. PP takes a long time to degrade in the landfills and may take 20-30 yeas to completely decompose. When PP leaks to the environment, it will slowly release microplastics (1 μm – 5 mm), and they can enter the natural ecosystems and affect the aquatic food chains. Considering the increasing number of single-use disposable mask wastes being disposed every year, the potential environmental problem is vast. The search for reusable, bio-renewable and bio-degradable materials that can function similarly to poly(propylene) materials is in urgent needs. Thus, replacing PP with lignin in some applications could not only reduce the use of PP, but also enhance the physical properties of polymer, such as tensile strength and bio-degradability.

Solving two problems with one solution

This study explores the potential of using electrospun lignin to produce nano-porous fibers, which can be used for face masks or air filtration materials. Since lignocellulose materials are abundant in nature, renewable, and essentially costless, it is highly urgent to explore these types of materials as an alternative to PP which are solely derived from fossil resources as well as alleviating the wood waste problem in Hong Kong.

Figure 1 a) Autoclave at THEi for lignin extraction from wood wastes. b) Separation of lignin (upper layer in *m*-THF) and xylose (lower layer in oxalic acid/water mixture). c) Extracted lignin from Pinewood.

Results

Lignin extraction:

Lignin were extracted by two different methods to produce spinnable lignin materials, such as alkaline lignin and organosolv lignin. For example, the Organosolv and Klason method is a very simple strategy to obtain lignin with medium to low molecular weight (MW = ~ 2000 – 3000 g/mol). However, under high acidity media, such as using inorganic acids, such as HCl(aq) or H_2SO_4(aq) and ethanol as the organic solvent, some of the ether linkages will be selectively cleaved and lead to significant degradation leading to a lower molecular weight of lignin. The high acidity will also lead to the degradation of polysaccharides and the formation of humins, which will complicate the final composition of obtained lignin. Based on this, we later used a milder organic acid such as oxalic acid/water mixture as the extraction reagent at 140ºC for 3 hours in an autoclave. In addition, taking advantage of the immiscible nature of *m*-THF solvent and oxalic acid, we have successfully isolated pure lignin using an autoclave at THEi (**Figure 1a**). The lignin is in the *m*-THF layer and the xylose components are retained in the oxalic acid/water mixture layer (**Figure 1b**). Higher molecular weight of lignin MW (4000 – 6000 g/mol) can be obtained and at the same time, xylose was also preferentially obtained as a desired product. The pure lignins are isolated in pure crystalline form, as shown in **Figure 1c**.

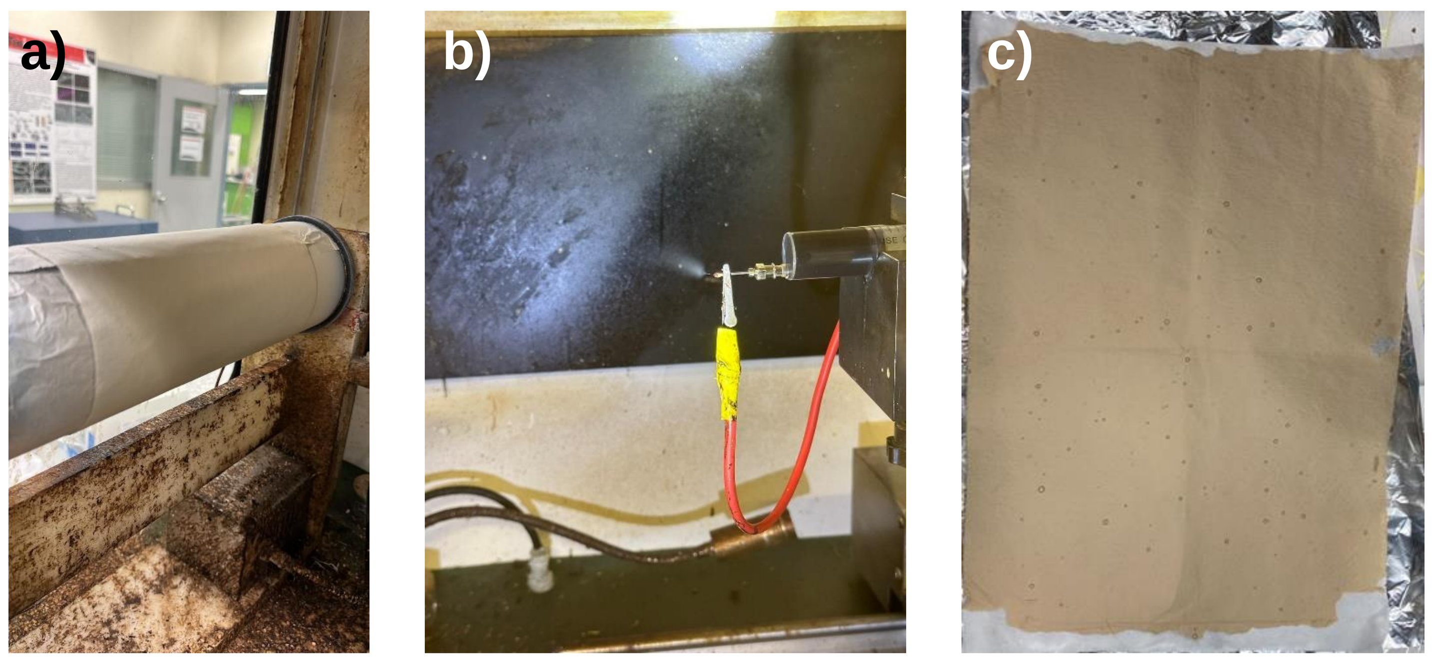

Figure 2 a) Materials being electrospun onto the receiver; **b)** setting of the correct voltage difference and the injection rate; **c)** as-spun lignin-derived fiber.

Electrospinning: With suitable blending with biodegradable polymer such as poly(lactic acid), the lignin can be electrospun into fibrous materials. For example, the following condition was adopted:

Materials: 7.35wt% PLA/PAN/Lignin 50/40/10 (95%) and Triclosan 5% in 70mL DMF (**Figure 2a**)

Electrospinning condition: Voltage range = -10.97 kV to 12.88 kV; Rate of injection = 0.04 mm/min (**Figure 2b**)

Testing: Three samples were tested (**Figure 2c**) and the anti-bacterial activity were found ranging from 3.07 to 7.30, equivalent to a reduction of 99.91% – >99.99% of the tested bacterial species, as shown in **Table 1**. The bacterial filtration efficiency (BFE) was also tested and it could ready 99.9% efficiency, according to ASTM standard: F2101-19.

Table 1 Antimicrobial efficiency.

Ration of the blended sample (PLA:lignin)	Antimicrobial properties (log scale)	Antimicrobial properties
90:10	3.07	99.9%
80:20	7.30	99.1%
70:30	3.60	99.9%

Conclusion

Polymer blend of lignin with biodegradable polymers have been successfully electrospun into nano-fibrous materials for filtration purposes.

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