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From Wool Waste to Clean Air: A Green Sandwich Membrane Solution

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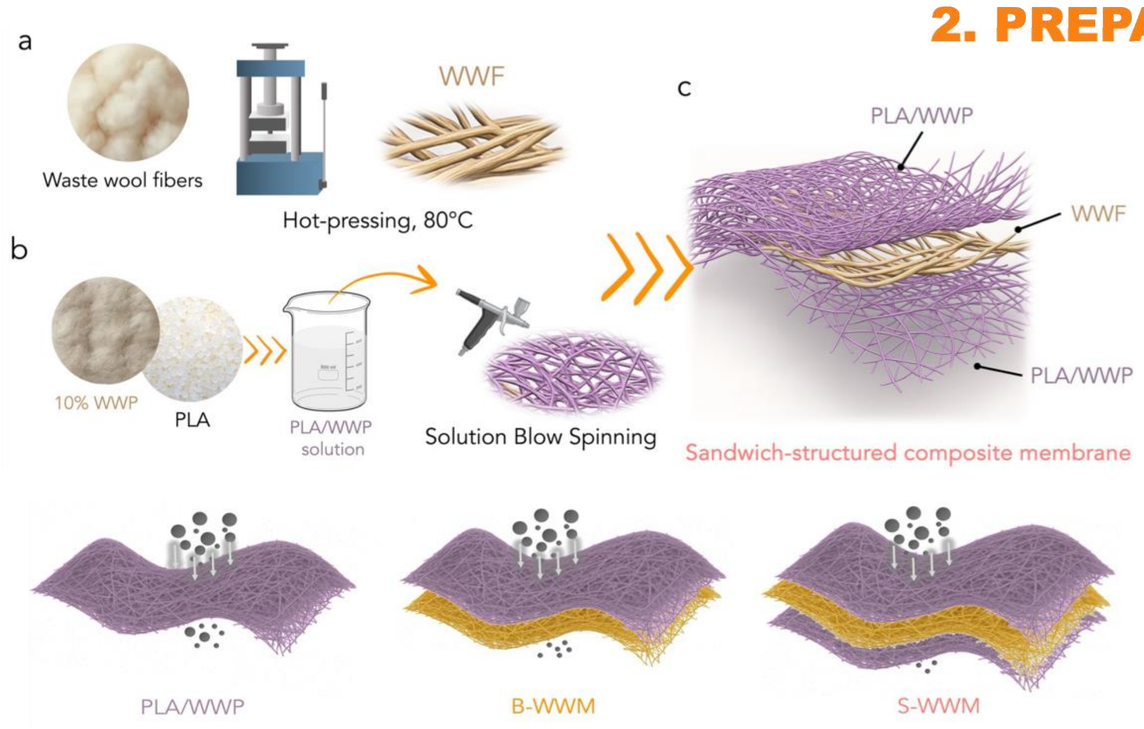
1. INTRODUCTION

Air pollution due to fine dust particles remains a pressing environmental challenge. To reduce the environmental footprint of air filtration technologies, it is crucial to develop solutions based on biodegradable polymers blended with natural fillers, ideally sourced from waste materials, to create efficient, durable, and reusable air filters. The membranes proposed in this work are characterized by the unique properties of wool fibers, such as excellent breathability and mechanical strength combined with high filtration efficiency achieved by PLA composite fibers.

2. PREPARATION OF THE FILTERING MEMBRANES



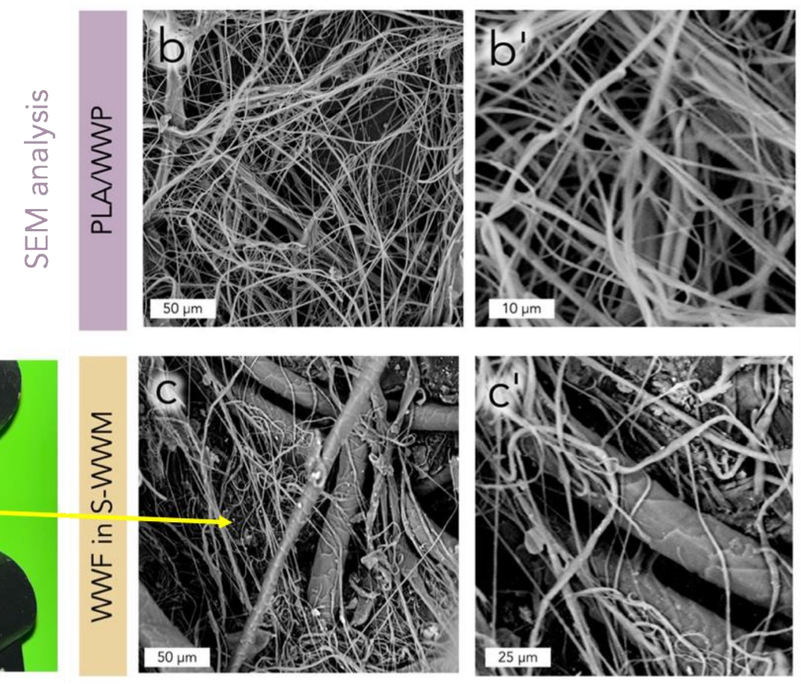
Innovative and green filtering membranes based on waste wool fibers (WWF) were produced by combining a central layer of hot-pressed wool fibers with two external layers of composite fibrous membrane (PLA/WWP) based on polylactic acid (PLA) and waste wool powder (WWP) obtained by solution blow spinning (SBS) technique.

The bilayer waste wool-based membrane (B-WWM) was prepared by spinning PLA/WWP dispersion directly onto one side of the previously obtained WWF mat.

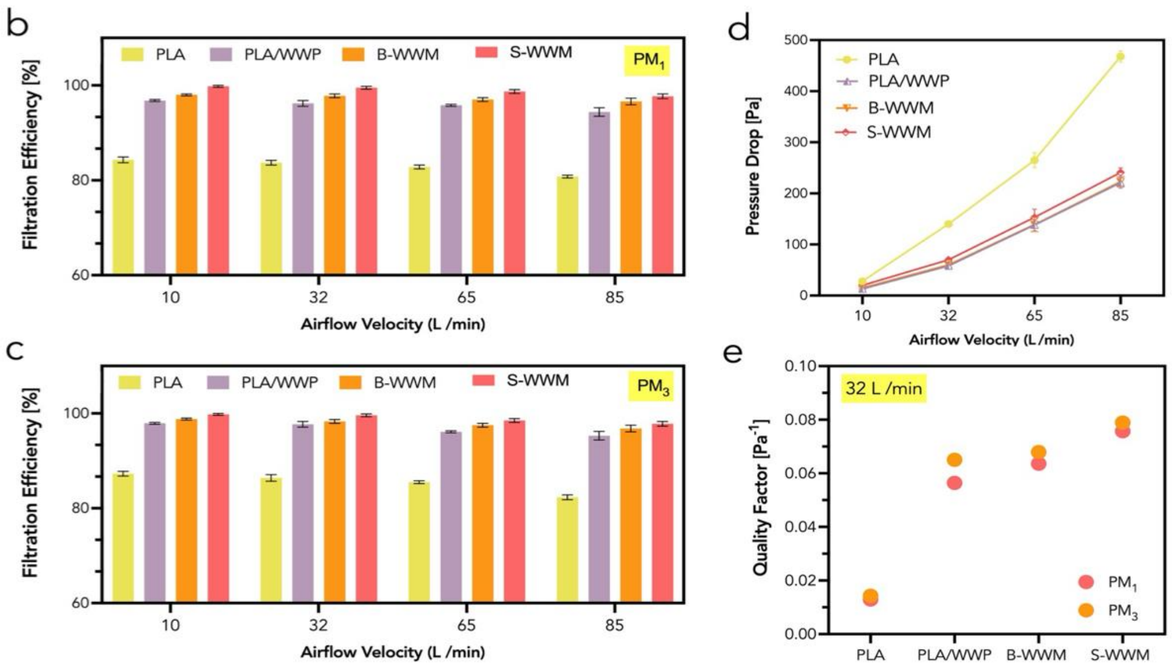
Sandwich-structured membrane (S-WWM) was prepared by spinning PLA/WWP dispersion directly onto both side of WWF mat.

3. CHARACTERIZATION OF THE MEMBRANES

The addition of WWP improved the viscosity of the spinning solution, leading to thinner and more uniform fibers, which can enhance the capture efficiency of fine particles.
Peeling test was carried out. The results showed a stable interfacial behaviour between the layers with a mechanically-interlocked system. The membrane remains stably attached to the substrate, ensuring the integrity of the layered system during handling and application.
After PLA/WWP layer was peel off, WWF still present some PLA/WWP strictly adherent to them.



4. AIR FILTRATION PERFORMANCES



Air filtration efficiency of pure PLA and wool based composite membranes were investigated by exposing them to particles (PM_1 and PM3) generated by burning incense at airflow rate of 10, 32, 65 and 85 L/min. Thanks to the combination of small pores and low packing density, S-WWM exhibited the highest filtration efficiency of 99.5% and pressure drops of 70 Pa at flow rate of 32 L/min. The same trend has been observed also for PM_3. Moreover, the membrane maintained filtration stability up to 5 reuse cycles and durability under high humidity conditions.
Most of the particles are captured by the first layer of the sandwich structure (PLA/WWP windward a). The smaller particles that manage to pass through this layer are largely intercepted by the intermediate layer (WWF windward). Only a few of the finest particles can reach the second PLA/WWP layer, which, due to its fibrous structure, is still able to capture the PMs.

5. CONCLUSIONS

The S-WWM exhibited the highest filtration performance that remained almost stable across a wide range of flow rates, temperatures, and relative humidity levels. The membranes also demonstrated excellent mechanical properties and good reusability. These findings confirm the potential of wool-based sandwich membranes as durable, reusable, and high-performance air filtration materials, offering a promising route for the valorization of natural and waste-derived resources in sustainable environmental applications.