

Project title: Transparent, Recycled Polyurethane Face Masks: Advancing Circular Economy and Communication Through Nano-Fiber Filtration

Industry partner(s): Vision Composites Inc.

Researchers: F. Gholamreza, R.J. Krishnamurthy, F. Rahimi, B. Crawford, M. Kashani, A. Hosseini, A.S. Milani

Introduction & Background:

Respiratory protective equipment (RPE) is often recommended, e.g. in specific healthcare settings or during a pandemic, to minimize the risk of exposure to various airborne respiratory infectious diseases. The RPEs cover the mouth and nose to impede the spread of airborne particles generated by infectious patients. They are also used to prevent healthcare personnel from being contaminated by staff-generated nasal and oral droplets expelled during speaking, coughing, and sneezing, as well as protect them from splashes and sprays during operations¹.

During the recent SARS-CoV-2 pandemic, the standard opaque medical masks posed a challenge to effective communication in healthcare settings, especially for individuals with loss of hearing and others who rely on visual cues or lip/speech reading. The availability of a multilayer medical mask (two layers and an additional middle filter layer) with a breathable, transparent layer covering perioral regions (human lip and the areas in close proximity of the lip) can significantly facilitate the communication of these individuals.

This research program aims to create a face mask transparent layer made from recycled polyurethane and enhance the properties of the product by employing and assessing laser milling and lithography techniques for procuring the nano-fiber air filter layer of the mask^{2,3}. Using these new techniques, nanosized holes with a controlled positioning and density can be created, hence potentially yielding a transparent layer with a relatively higher air permeability and filtration capability. The overarching aim of this is to perform an extensive experimental study to find a suitable process that can produce a transparent porous film with improved breathability and thermo-physiological comfort, along with other pertinent properties (e.g. inflammability and UV/aging resistance), as compared to the commercially available face masks.

Relevance to Circular Economy:

This project enhances the circular economy by using recycled polyurethane which diverts waste from landfills and reduces the environmental footprint of polyurethane disposal. It contributes to closing the material loop, ensuring that polyurethane, which is traditionally difficult to recycle, is reprocessed into a valuable product. In addition, a breathable, transparent barrier layer designed for reuse or further recyclability aligns with circular economy principles.

Methodology:

In order to produce transparent sections of masks that are highly breathable, nano-sized holes must be created with high precision and density. Laser milling techniques are used to achieve this goal, such as a focused beam of laser light to vaporize a small material area, leaving a hole. The flammability test (ASTM D6413-22), pressure drop test across the transparent pre-oral material (ASTM D 737), as well as comfort-related properties such as water vapor permeability (ISO 15496/JIS L1099), thermal resistance, and Evaporative resistances of the mask (ASTM F1291-22 and ASTM F 2370-22) were performed. Submicron particulate filtration efficiency performance of the transparent pre-oral material was conducted in collaboration with Nelson Labs⁴. Figure 1 illustrates the project flow path for developing high filtration (>98%) surgical face masks with perioral transparent porous film.

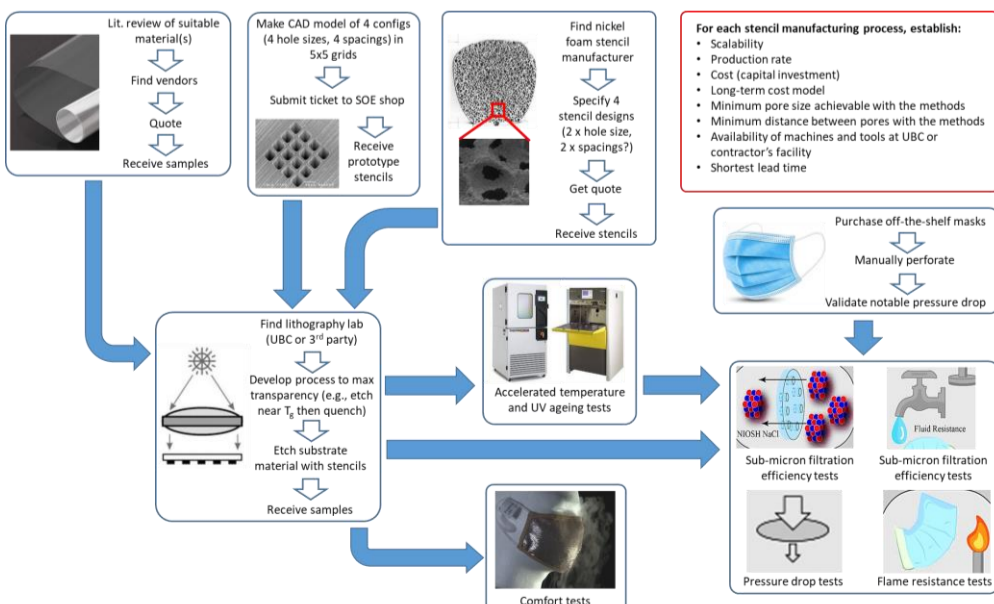


Figure 1: Project flow designed for developing a perforated, transparent polymer sheet prototype

Results & Discussion

This study investigated the development of a transparent medical mask using laser milling and lithography techniques to enhance both breathability and transparency while maintaining high filtration efficiency. By creating precision holes of 0.075 mm (±0.005 mm) diameter with 0.150 mm pitch distance (Figure 2), an optimal balance between filtration and airflow was achieved, evidenced by a 98.2% filtration efficiency against 75 nm particles and a 47% reduction in breathing resistance compared to earlier electrospun prototypes. Femtosecond laser ablation proved more precise than conventional methods, resulting in superior hole uniformity (±0.002 mm standard deviation) with minimal heat-affected zones at 220 fs pulse duration. Mechanical integrity and flame resistance remained within medical-grade standards—even with perforations—while accelerated aging tests (70°C for 6 days, plus UV exposure) showed only a 3.5% drop in filtration efficiency and negligible change in breathability. These perforated films also excelled in light transmittance (87% vs. 60% for electrospun materials), effectively supporting visual communication needs in clinical settings.

Subsequent analyses highlighted the economic feasibility of scaling the laser milling process to produce around 1,200 transparent film sections per hour, meeting commercial targets of 12 million masks annually with a single multi-beam parallel setup (capital cost of \$120,000–150,000). In addition to meeting or exceeding requisite medical performance benchmarks, the laser-milled masks demonstrated significantly improved thermal comfort, with evaporative resistance (Ret) values of 8.5 Pa·m²/W compared to 14.3 Pa·m²/W in previous materials.

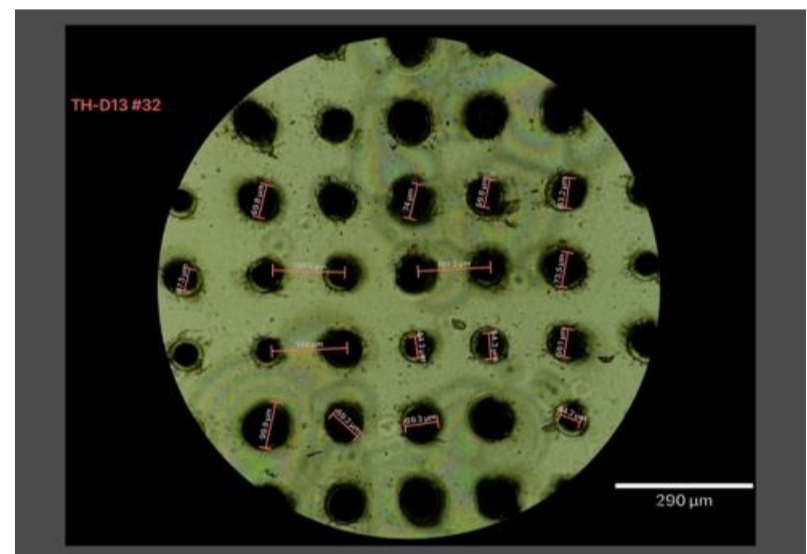


Figure 2: Perforated transparent recycled polyurethane with the precision of 0.075 mm (±0.005 mm) diameter with 0.150 mm pitch distance

Conclusion & Next Steps

This project successfully achieved the desired hole size and pitch distance in the recycled polyurethane transparent sheet, with a signal test confirming the uniformity and consistency of the drilled holes. Overall, the optimized prototypes mark a significant step forward in transparent mask technology, balancing critical parameters—transparency, breathability, and filtration—to fulfill the dual needs of effective infection control and improved communication in healthcare environments. The following steps of the project can be referred to as the development of an appropriate evaluation method to (b) run trials and validate the transparency of the perforated transparent layer (e.g., when two individuals wearing the masks and communicate with each other via lip/speech reading, they should be able to clearly understand each other). In addition, assessments and recommendations will be made to enhance the scalability and production rate of the mask for commercialization of the product.

References:

- Gholamreza, F., et al., *Enhanced protection face masks do not adversely impact thermophysiological comfort*. PLoS one, 2022. 17(4).
- Konda, A. et al. *Aerosol Filtration Efficiency of Common Fabrics Used in Respiratory Cloth Masks*. ACS Nano 14, 6339–6347 (2020).
- Montgomery, D. C. *Design and Analysis of Experiments*, NY: Wiley, 2013
- ASTM, *D6413/D6413M-22 Standard Test Method for Flame Resistance of Textiles (Vertical Test)*. 2022: West Conshohocken, PA.
- Duncan S, Bodurtha P, and N. S, *The protective performance of reusable cloth face masks, disposable procedure masks, KN95 masks and N95 respirators: Filtration and total inward leakage*. PLoS ONE, 2021. 16(10): p. e0258191.