FIRST STEPS TO N95: LOW-TECH AND ADAPTED EQUIPMENT FOR THE AUTONOMOUS DEVELOPMENT OF PLASTIC MICROFIBERS FOR MASK FILTRATION

PRIMEIROS PASSOS PARA O N95: EQUIPAMENTO DE BAIXA TECNOLOGIA E ADAPTADO PARA O DESENVOLVIMENTO AUTÔNOMO DE MICROFIBRAS PLÁSTICAS PARA FILTRAÇÃO DE MÁSCARAS

PRIMEROS PASOS HACIA EL N95: EQUIPOS DE BAJA TECNOLOGÍA Y ADAPTADOS PARA EL DESARROLLO AUTÓNOMO DE MICROFIBRAS PLÁSTICAS PARA LA FILTRACIÓN DE MASCARILLAS

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ABSTRACT

The pandemic has brought unprecedented obstacles. One of the critical challenges was the shortage of Personal Protective Equipment (PPE). Additive manufacturing has emerged as a viable solution to address the PPE shortage. Developed 3D-printed masks were a way to combat market shortages, but producing the filter element remains an obstacle. This study documents research into the feasibility of applying the plastic casting technique using centrifugal melt spinning, a possible way to replicate existing processes. The concept is simple and similar to how cotton candy is made. The aim is to propose possible ways of using distributed manufacturing, recycling, and adapting local infrastructure to manufacture viable filters, comparing them with those produced using traditional methods.

KEYWORDS

Cotton Candy; Melt Spinning; Filter.

RESUMO

A pandemia trouxe obstáculos sem precedentes. Um dos desafios críticos foi a escassez de Equipamentos de Proteção Individual (EPI). A manufatura aditiva emergiu como uma solução viável para enfrentar essa carência de EPIs. Máscaras desenvolvidas por impressão 3D foram uma forma de combater a escassez no mercado, mas a produção do elemento filtrante permanece um obstáculo. Este estudo documenta a pesquisa sobre a viabilidade da aplicação da técnica de moldagem de plástico por centrifugação de fusão ("centrifugal melt spinning"), uma possível maneira de replicar processos existentes. O conceito é simples e assemelha-se ao modo de fabricação do algodão-doce. O objetivo é propor formas de empregar manufatura distribuída, reciclagem e adaptação da infraestrutura local para produzir filtros viáveis, comparando-os com aqueles obtidos por métodos tradicionais.

PALAVRAS-CHAVE

Algodão-Doce; Fiação por Fusão; Filtro

RESUMEN

La pandemia ha presentado obstáculos sin precedentes. Uno de los desafíos críticos fue la escasez de Equipos de Protección Personal (EPP). La fabricación aditiva ha surgido como una solución viable para abordar esta falta de EPP. Las mascarillas desarrolladas mediante impresión 3D fueron una forma de combatir la escasez en el mercado, pero la producción del elemento filtrante sigue siendo un obstáculo. Este estudio documenta la investigación sobre la viabilidad de aplicar la técnica de moldeo de plástico mediante hilado centrífugo fundido ("centrifugal melt spinning"), una posible manera de replicar procesos existentes. El concepto es sencillo y es similar al modo en que se produce el algodón de azúcar. El objetivo es proponer vías para emplear fabricación distribuida, reciclaje y adaptación de la infraestructura local para fabricar filtros viables, comparándolos con los obtenidos mediante métodos tradicionales.

PALABRAS CLAVE

Algodón de Azúcar; Hilado por Fusión; Filtro

1. INTRODUCTION

The COVID-19 pandemic, caused by the SARS-CoV-2 coronavirus, has triggered an unprecedented global public health crisis, affecting nearly every aspect of human life. With easy transmission and initially unknown transmission routes, the number of hospital cases rose sharply, creating demand for PPE that exceeded available stocks. PPE such as masks, gloves, aprons, and face shields became vital in preventing virus transmission, protecting users, and mitigating community spread. Governments faced shortages of this equipment, including N95 respirators, due to increased global demand that strained supply chains and created challenges in meeting healthcare workers' needs (Ehrlich et al., 2020).

The limited availability of PPE not only endangered frontline personnel but also hindered effective COVID-19 patient management, highlighting the critical importance of ensuring a stable and sufficient supply of protective equipment during health crises (Valdez et al., 2022). In response to PPE shortages, designers and institutions implemented innovative solutions, research, and strategies to address supply gaps and protect healthcare staff. Some hospitals resorted to reusing masks or improvising with adapted resources to cope with limited equipment availability (Grossman et al., 2020). Additionally, initiatives such as disinfecting N95 respirators using vaporized hydrogen peroxide were introduced to extend PPE usability and optimize resource utilization during the pandemic (Fram et al., 2020). The challenges presented by PPE shortages underscored the need for efficient acquisition, distribution, and use of protective equipment to safeguard healthcare professionals (Schmidt et al., 2021).

PPE shortages during the pandemic had far-reaching consequences for healthcare workers, requiring alternative approaches and concerted efforts to address supply chain disruptions and ensure universal safety. The challenges highlighted the importance of proactive planning, resource allocation, and decentralized production alternatives to mitigate shortages and protect populations during public health emergencies.

With this increased demand, new manufacturing techniques played a key role. The use of additive manufacturing technology emerged as a viable solution to resolve the severe equipment shortages during the COVID-19 pandemic. By leveraging 3D printing capabilities, communities could quickly produce essential PPE in response to supply shortages (Amir & Amir, 2022). Custom 3D-printed face masks were also developed to address the lack of commercially available FFP2/3 masks by offering personalized solutions tailored to specific needs (Swennen et al., 2020). These masks typically consisted of reusable 3D-printed components combined with filter elements, providing an alternative production approach during epidemic crises (Swennen et al., 2020).

2. THE RESEARCH

Researchers at BioDesign at PUC-Rio are developing new PPE, such as filtering mask models that use surgical mask fabric as the filtering element (Yamaki et al., 2022 - Figure 1). The use of surgical masks as filters was based on laboratory breathability tests, which indicated that surgical masks were highly permeable and comfortable for breathing. This, combined with their effective filtration, led to research into respiratory masks aimed at solving the problem of facial sealing, eliminating unfiltered air leakage.

Although using surgical masks satisfied researchers' air filtration requirements during mask development, progress remains incomplete regarding the goal of producing respiratory masks entirely independent of conventional production chains. Designing filter manufacturing methods represents an important step.

The introduction of filter manufacturing could enable complete mask production. There are many techniques for developing air filters by controlling air passage through fabrics, whether woven or non-woven, composed of synthetic or natural fibers. One method for producing synthetic fibers is centrifugal plastic melt spinning, where fibers are made into fabric and electrically charged to enhance effectiveness.

When implementing centrifugal melt spinning (Bandi, 2020) on a smaller scale, specialized machines are unnecessary due to its conceptual simplicity. This technique, already implemented and published, involves melting and casting plastic, similar to the cotton candy process. Instead of fine sugar fibers, researchers can create plastic polymer fibers.

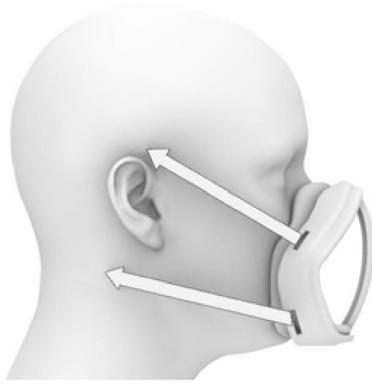

Figure 1: Mask made by additive manufacturing using a surgical mask as filtering media.
Source: Yamaki et al., 2020.

3. EMERGENCY FILTER MANUFACTURING

Bandi (2020) explores applying the cotton candy technique to create electrostatically charged filter meshes compared with commercially available masks. The study presents the experimental method of electrocharging mask filters using corona discharge treatment (CDT) (Bandi et al., 2021). By subjecting these locally manufactured materials to electrical discharges, the research aims to enhance the filtration performance of full-face respirators, increasing their protective capabilities against airborne particles and pathogens.

Molina (2020) also examines implementing centrifugal melt spinning to manufacture filters comparable to N95 masks. The study focuses on developing and applying the fiber production technique using modified cotton candy machines. It demonstrates the feasibility of distributed manufacturing using everyday materials to meet growing demand for respiratory protective equipment. The author also discusses this approach's advantages, such as scalability, sustainability, and cost-effectiveness.

Building on these authors' developments, this study investigates the feasibility of applying the plastic casting technique through the cotton candy manufacturing method to produce protective mask filters. The objective is to propose ways of using distributed manufacturing, recycling, and adapting local infrastructure to manufacture viable filter elements, comparing them with those produced by traditional methods.

4. MATERIALS AND METHODS

4.1. Research through Design

The research uses the "Research through Design" (RtD) method, a systematization that integrates research and design processes to create new knowledge and solutions. It comprises iterative analysis, design, development, and implementation of products in authentic contexts, leading to the creation of contextually sensitive design principles and theories (Basballe & Halskov, 2012). This approach is closely related to research through practice, where the creation of objects drives knowledge generation.

RtD uses praxis and design thinking as a methodology and research model in product creation. Unlike conventional design practice focusing on commercially successful products, design researchers use RtD to create artifacts intended to answer specific research questions (Zimmerman et al., 2007). It involves prototyping, testing, and refining solutions to solve complex problems or develop new products. This methodology emphasizes integrating design thinking, experimentation, and analysis to generate new knowledge and practical outcomes.

The value of RtD lies in its ability to bridge the gap between research and design, as emphasized in studies about research through design dynamics (Basballe & Halskov, 2012). RtD involves creating objects while developing protocols, descriptions, and guidelines to ensure process reliability, repeatability, and validity (Reeves, 2015). RtD is a multifaceted methodology that promotes innovation and practical solution development. By integrating diverse research methods, purposeful sampling strategies, and interdisciplinary collaboration, researchers can address complex problems and generate contextually relevant solutions.

4.2. Cotton candy method

The central idea, explored in the works of Bandi (2020) and Molina (2020), is to repurpose standard equipment by adapting it for alternative uses, adjusting specifications to pandemic realities. When detailing necessary adaptations for cotton candy machines, Bandi suggests component replacements if original machines are unavailable. According to the study, small commercial cotton candy machines typically use electric heating elements, while larger ones are gas-powered. Most operate at 160-175°C, below the required 280-340°C range for generating pure PP or PP-PS yarn (the thermoplastics used in his experiment). He recommends modifying the machine's heating circuits to achieve higher temperatures.

For custom-built machines, developing an adjustable electric heating element is preferable if technical knowledge is available. A simpler alternative uses a gas torch, adjusting flame distance from the emitter cup while monitoring temperature with a kitchen thermometer. Regarding motors, commercial machines reach 3000-4500 rpm - sufficient for fiber formation - but Bandi suggests upgrading to 15,000 rpm for optimal results.

4.3. Machine components

Figure 2: Typical cotton candy machine available in Brazil.
Source: INOVAMAQ, 2024.

The traditional cotton candy machine contains these key elements: a central motor rotating a perforated emitter cup with a heating element (Figure 2). When activated, the cup rotates at high speed, melting its contents, which extrude through holes as strands that accumulate on the surrounding container walls. Based on author recommendations and researcher adaptations, the modified machine incorporated these substitutions:

4.3.1. Motor

The standard cotton candy machine motor operates at 4500 rpm – the minimum speed required for fiber production. However, Bandi (2020) recommends achieving up to 15,000 rpm for optimal results. To meet this specification, researchers employed an 830W angle grinder capable of reaching 11,000 rpm, nearing the upper range suggested in the study. A dimmer was integrated into the system to precisely regulate speed by adjusting voltage and controlling grinder rotations (Figure 3).

Figure 3: Skill 830W grinder and voltage controller Dimmer used on the machine.
Source: Ritec e loja EliteNet, 2024.

4.3.2. Central emitter cup

The emitter cup is mounted and rotates on the motor shaft, containing the material (sugar for conventional machines or plastic in this application) that melts to form fibers. While Bandi (2020) suggests using a halved soda can as an emitter, initial tests revealed this couldn't withstand the grinder's rotational speeds (up to 11,000 rpm). We initially substituted it with a halved powdered milk can due to its more rigid metal structure, but this also proved insufficient. The final solution employed a 300ml steel mug cut in half, providing greater thickness and structural integrity through its seamless deep-drawn construction.

For secure attachment, a 2.5mm-thick diamond cutting disc was used to mount the emitter cup to the grinder shaft. This disc features 12 concentric holes (plus the central axis) that allow screw-fastening to the cup, significantly improving assembly stability (Figure 4).

Figure 4: 4.½" diamond disc and 300ml steel mug used to assemble the machine.
Source: Loja do Mecânico e Mandiali, 2024.

4.3.3. Temperature control

Following methodological recommendations from the literature, temperature was monitored using an infrared (laser) culinary thermometer. This instrument was selected for its combination of practicality, accessibility, and precision – critical factors for experimental work.

The non-contact laser thermometer not only enabled accurate real-time temperature measurements but also ensured reliable, reproducible results, thereby enhancing the overall data accuracy (Figure 5).

Figure 5: Digital laser thermometer and 2000W thermal blower used to assemble the machine.
Source: Maquinbal e Loja do Mecânico, 2024.

4.3.4. Emission drilling

Bandi's (2020) publication documents the use of an 87-gauge drill (0.254mm diameter holes) while suggesting that smaller perforations could yield superior results. In our initial prototype, we drilled 2mm diameter holes in a powdered milk can. For the second iteration, we created 15mm diameter holes in the can wall and installed a three-layer folded mesh from commercial cornmeal sieves - the finest available option. These sieves typically feature 16-mesh steel screens composed of 0.45mm diameter wires with 1.13mm openings. While this configuration served as our primary solution with the steel mug emitter, we ultimately implemented an even finer mesh as originally intended.

4.3.5. External recipient

For fiber collection, researchers employed a 40-liter aluminum pan with the following dimensions: 22 cm base diameter, 32 cm mouth diameter and 15 cm height. A central hole was drilled in the pan's base to accommodate the grinder's rotating axis. The assembly was mounted on a 43 cm × 28 cm MDF baseboard (20 mm thickness), with both the aluminum pan and grinder securely affixed to this platform (Figure 6).

Figure 6: Cornmeal sieve and 40-liter aluminum pan.
Source: Tegape Telas, 2024.

4.4. Used Materials

Figure 7: Recycled 4mm polypropylene pellets and leftover PLA filament.
Source: The authors.

For the experiments, researchers utilized both recycled polypropylene pellets and PLA filament scraps from previous 3D printing jobs (Figure 7). While polypropylene remains the recommended polymer for filter production, PLA was included in this study phase due to high availability from laboratory waste streams (including failed prints and support structures) and potential applications in textile manufacturing through fiber spinning. The use of PLA waste aligns with broader material recycling initiatives beyond just filter production.

5. EXPERIMENTS

The initial prototype iterations served dual purposes: they provided valuable methodological insights into machinery adaptation while highlighting critical safety considerations when repurposing tools beyond their intended design specifications. During these tests, researchers exercised extreme caution - a necessary precaution when modifying equipment for unanticipated applications, as manufacturers cannot guarantee performance under such conditions.

The first configuration used a modified powdered milk can, with researchers initially confident that its welded seams could withstand the grinder's high rotational speeds (Figure 8). While preliminary tests proved successful, subsequent operation revealed structural limitations: during one trial, the can's soldered joint failed catastrophically. The base separated from the sidewall (remaining attached to the mounting disc), propelling metal fragments outward at high velocity (Figure 9). Strict adherence to safety protocols - including mandatory use of the protective enclosure and personal protective equipment - prevented injuries during this incident.

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Figure 8: Emitter cup used in the first tests. Researchers manufactured the first two attempts using powdered milk cans, first making small holes in the can itself with a drill (left) and then making larger holes and using a cornmeal sieve as a screen to disperse the threads.
Source: The authors.

Therefore, these safety protocols remain in effect: The equipment must only be operated with the reinforced safety lid properly secured. Operators are required to wear full personal protective equipment (PPE), including (1) a NIOSH-approved N95 respiratory mask to filter airborne plastic particles, (2) hearing protection to mitigate loud engine noise, (3) safety goggles combined with a face shield for complete facial protection, and (4) heat-resistant gloves when handling high-temperature materials.

Figure 9: An accident occurred with the use of a can. Only the bottom of the can remained fixed to the cutting disc.
Source: The authors.

Figure 10: Detail - the space between the bottom of the cup, the base disc (left), and the stove used to help melt the plastic (right).
Source: The authors.

The initial experiments using only the thermal air blower proved unsuccessful. Researchers mounted the can using spacer nuts between its base and the disc to maintain the grinder shaft's functionality as the emitter. However, during rotation, the emitter cup created air vortices that disrupted the hot airflow, preventing proper plastic melting. To address this, an electric stove was implemented as an additional heat source, with its heating element positioned above the emitter cup to radiate heat downward (Figure 10).

This modified approach ultimately failed to produce satisfactory results, as it generated excessively high temperatures with no means of precise temperature regulation or directional heat control (Figure 14). The plastic became overly fluid, causing it to eject prematurely when the machine was activated. Instead of forming the desired fibers, the molten material simply accumulated on the walls of the collection container (Figure 11).

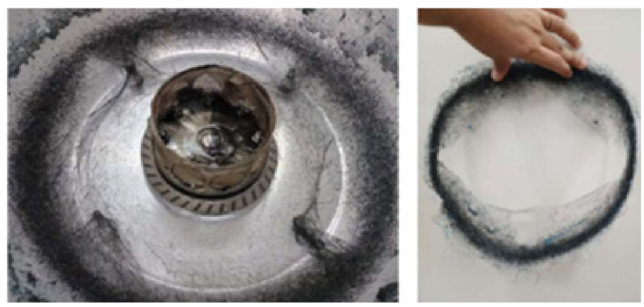

Figure 11: The high temperature melted the plastic, leaving it very fluid, leaving a solid residue on the container wall.
Source: The authors.

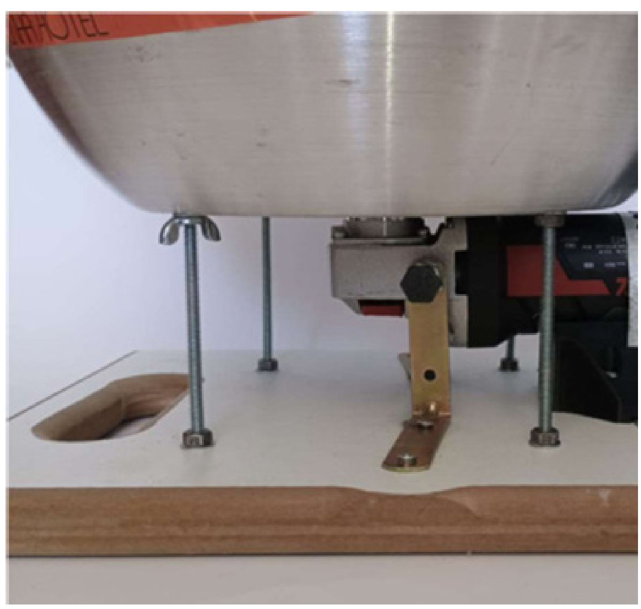

Figure 12: Detail of the base assembly.
Source: The authors.

To provide stability while maintaining portability, researchers used a 20 mm thick MDF sheet as a base, incorporating a cut-out carry handle (Figure 12). Due to significant engine vibration, the team strongly recommends permanently securing the machine to a workbench using clamps during operation. The grinder was mounted using a perforated steel band along with two angle brackets, all securely screwed to both the tool body and base. While the primary design utilized 3D-printed custom components through additive manufacturing to ensure perfect horizontal alignment, the study confirms that traditional wooden bases can serve the same purpose.

Figure 13 illustrates the complete assembly of the first prototype, with components listed in descending order: the 2000W heat gun (or hot air blower), followed by the 3mm MDF plate lid, electric burner, fixing nuts, modified powdered milk can (cut and perforated), spacer nuts, cutting disk, and finally the fixing screws.

Figure 13: Exploded view of the first construction of the machine.
Source: The authors.

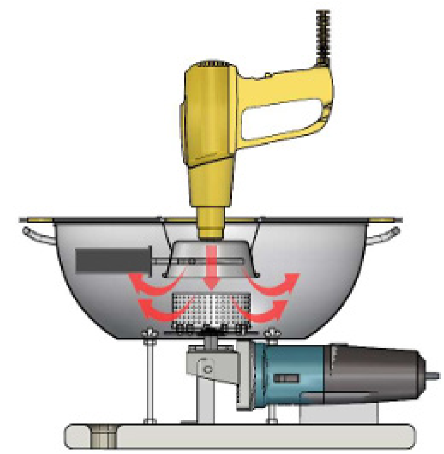

Figure 14: Section of the machine's first attempt. The red arrows indicate the hot air flow.
Source: The authors.

Figure 15: Mini pudding mold used to channel air. A hole was made in the central part for air passage.
Source: The authors.

Based on these findings, researchers determined the emitter cup must be mounted directly to the disc without spacer elements. Additionally, the air stream from the blower required proper channeling to minimize energy losses. An inverted aluminum pudding mold (10.5 cm top diameter, 7.5 cm base diameter, 5 cm height) was installed immediately above the emitter cup (Figures 14 and 15) to optimize airflow direction. This modification successfully directed the heated air stream into the plastic material within the cup, enabling proper extrusion through the mesh screens and achieving the intended fiber formation (Figure 18).

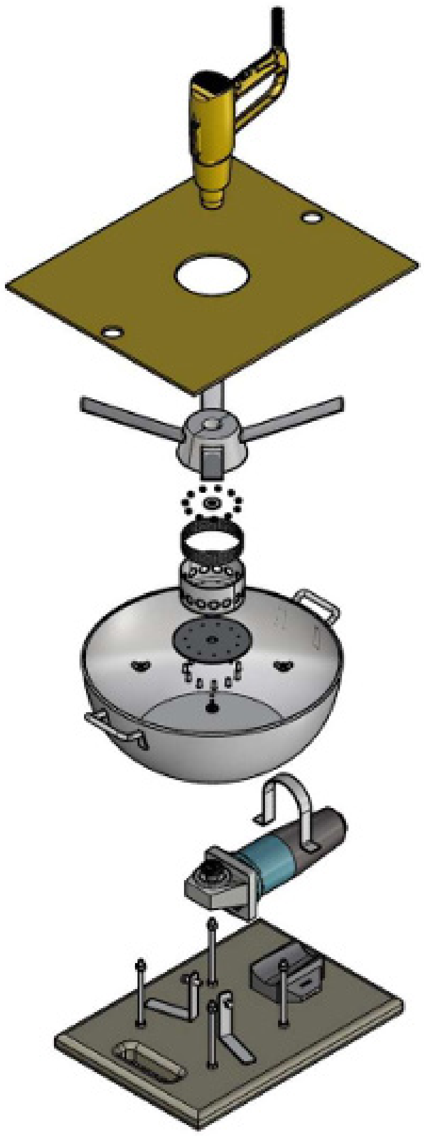

Figure 16: Exploded view of the construction of the new cotton candy machine.
Source: The authors.

The adapted cotton candy machine's complete assembly is shown in Figure 16, displaying all components in descending order from top to bottom. The configuration consists of: a 2000W heat gun (or hot air blower), followed by a 3mm MDF plate lid, an inverted pudding cup, the emitter cup fixing nuts and grinder center axle nut, the emitter cup itself, the cutting disk, the cup fixing screws, a 40-liter aluminum collection pot, the grinder fastener, an 830W angle grinder, the grinder base, a 20mm MDF board base, and finally the threaded bar used for pan fastening.

For proper assembly, the aluminum pot and grinder must first be securely anchored to the base. The modified emitter cup, which already incorporates the sieve screen, should then be attached to the cutting disc before mounting the complete assembly onto the machine's rotating shaft. The pudding mold requires connection to the pot walls using sheet steel strips that are permanently secured with rivets.

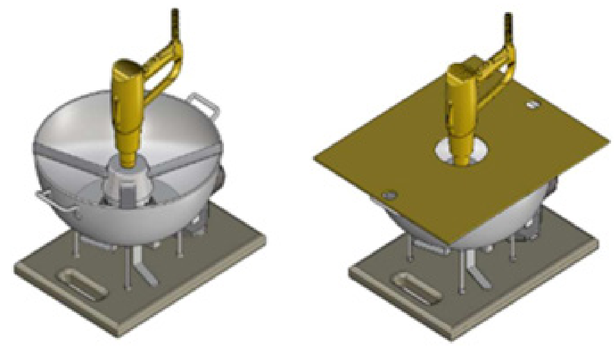

Figure 17: Final assembly of the machine without cover (left) and with cover (right).
Source: The authors.

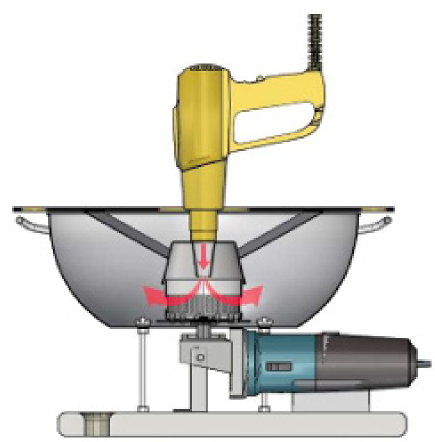

Figure 18: Hot air flow indicated by red arrows.
Source: The authors.

Through experimentation, the research team established the proper operating procedure: the motor should be activated only when the emitter cup contains plastic material. Preheating is strongly recommended to ensure the plastic melts properly and prevents premature ejection upon startup. Once prepared, the operator must securely close the lid (Figure 17) and position the blower vertically downward, directing airflow from the pudding mold (which is permanently affixed to the pan walls) into the rotating emitter cup. When operating at full speed, this configuration creates an efficient airflow pattern where heated air enters through the top of the cup and escapes through the side perforations, successfully generating the desired polymer fibers.

6. PRELIMINARY RESULTS

Polypropylene served as the initial test material during machine development. Using unprocessed PP pellets, researchers produced a preliminary fleece containing partially fused plastic fragments. During this early prototype phase (prior to implementing the airflow-optimizing pudding mold), material heating relied solely on an electric stove. This uncontrolled heating method led to inconsistent melting – while some polymer formed fibrous structures, excess heat liquefied portions of the material, causing uncontrolled ejection rather than proper fiber formation (Figure 19).

In subsequent tests using PLA filament after implementing directed airflow, fleece quality improved significantly. With its lower melting temperature (145°C), PLA demonstrated easier processing characteristics and more consistent fiber production, yielding promising preliminary results.

Figure 19: Fleece obtained with recycled polypropylene pellets (blue) and recycled PLA fleeces in black, white, and orange.
Source: The authors.

For preliminary analysis, the PLA fiber samples were examined under a digital microscope at 1000x magnification to measure their diameters, with direct comparison to fibers collected from an N95 mask filter (Figures 20 and 21).

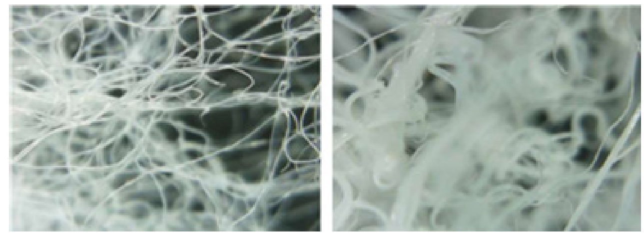

Figure 20: Magnification (x1000) of the media from the N95 mask used as control (left) and white PLA threads manufactured on the machine.
Source: The authors.

Figure 21: Magnification (x1000) of the PLA wires manufactured on the machine, black (left) and orange (right).
Source: The authors.

The initial visual analysis reveals that at identical magnification, the machine-produced PLA fibers demonstrate inconsistent uniformity and thickness compared to the polypropylene fibers from the N95 reference mask. While some PLA fibers approach the control sample's dimensions, others exhibit significantly larger diameters. This variation was anticipated, as the PLA samples represent preliminary production trials using different materials and screen hole diameters, manufactured without precise process control.

These findings confirm the need for further research refinement. However, this comprehensive documentation of early-stage experimentation proves valuable for identifying system limitations and guiding subsequent design improvements.

6.1. FILTER MANUFACTURING TRIALS

Despite not achieving optimal fleece quality, preliminary filter production trials were conducted with the available material. Importantly, while physical structure validation remains crucial, the final filters will require additional electrostatic charge enhancement via air ionizer treatment. Bandi (2020) specifically recommends exposing the polymeric fabric to isothermal loading for 10 minutes at a 1 cm distance from a domestic air ionizer - a process to be implemented once the filters meet preliminary specifications. Given the current limitations,

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research has focused on perfecting SMS fabric welding techniques for interim filter production.

The use of adapted welding equipment serves dual purposes: it functions as both a prototyping tool and a case study for distributed manufacturing solutions in resource-limited settings. Compared to specialized ultrasonic sewing machines (which are cost-prohibitive and scarce outside urban PPE factories), these adaptations can maintain higher PPE efficacy than conventional sewing methods.

The sublimation hot press emerges as the most viable option among tested equipment. More affordable and widely available in garment factories across diverse regions, these presses are typically used for customized textile printing (promotional items, sportswear, and fashion products). Their precise temperature and time controls enable accurate SMS welding without material degradation. Extensive testing has validated their application for various PPE components, including N95-style masks, 3D-printed mask filters, and surgical gowns (Figure 22). These experiments identified critical parameter dependencies for successful welding outcomes.

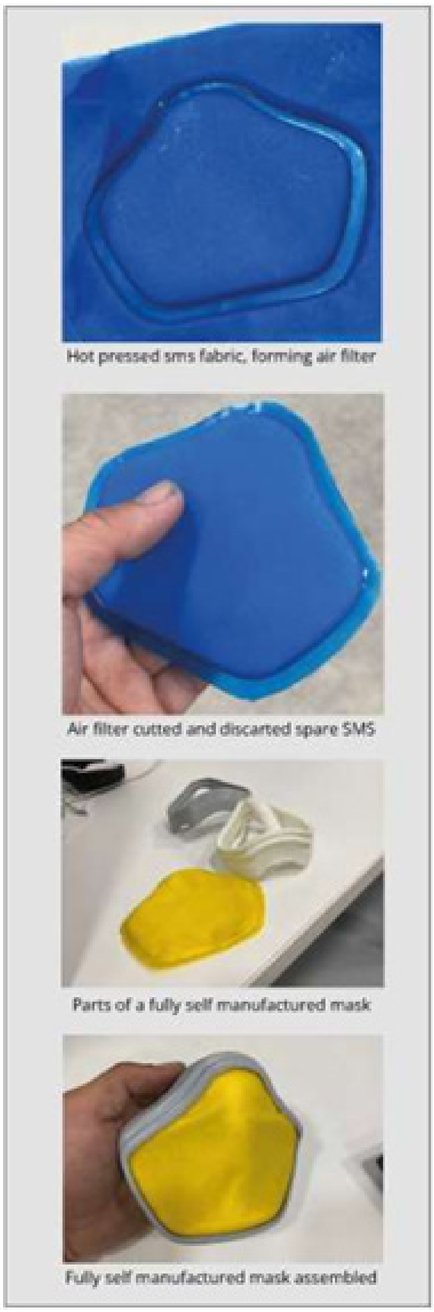

Figure 22: Welding studies using sublimation hot presses carried out on different personal protective equipment with filtering needs.
Source: The authors.

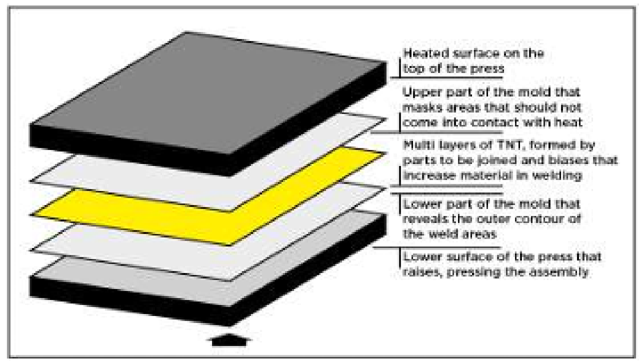

Figure 23: Schematic image of the layers to be organized for hot pressing in the sublimation press to weld the SMS.
Source: The authors.

Pure polypropylene (without additives) has a melting point of 170°C, though this can increase beyond 200°C with additives. Notably, the welding process requires lower temperatures than typical industrial processing methods - unlike extrusion or injection molding which operate between 210-270°C. Through systematic testing, researchers identified 175°C as the optimal pressing temperature, providing the best control within the evaluated 160-190°C range for the developed components.

It is important to note a temperature variation on the press's heated surface in your area. The intensity and uniformity of heat can vary from equipment to equipment, so calibration tests must be carried out based on the variation in the model and equipment used.

An important consideration is the inherent temperature variation across the press's heating surface. Heat intensity and distribution uniformity vary significantly between equipment models, necessitating device-specific calibration tests. The required pressing time depends directly on the set temperature and material thickness - as more layers require longer duration for complete heat penetration to achieve proper melting. This temperature-time relationship follows an inverse proportionality: higher temperatures permit shorter pressing times to prevent weld defects.

Excessive duration risks material degradation, causing holes and imperfections in both the weld zone and surrounding areas. Conversely, insufficient time prevents complete heat penetration, resulting in either partial melting of layers or failed bonding. Optimal parameters must account for both material properties and equipment characteristics. For the experimental trials, researchers employed 65-70 second cycles for smaller weld areas (≤25 cm^2) and 75-80 seconds for larger surfaces (>25 cm^2), establishing these as baseline values for the tested configurations.

Sublimation presses generate heat exclusively from their upper surface, requiring specialized molds to achieve localized heat application. Research findings indicate these molds must be constructed from rigid, thermally insulating materials and precisely cut to expose only targeted heating areas. Proper implementation involves alternating material layers with the mold during pressing, while ensuring thermal insulation through non-stick surfaces.

Optimal mold design incorporates a bleeding zone extending beyond the primary heat application area - a feature implemented in the final prototypes with 2cm bleed margins on all sides. For prototype development, researchers utilized 3mm MDF boards, laser-cut according to vector designs derived from the cutting templates (Figure 24).

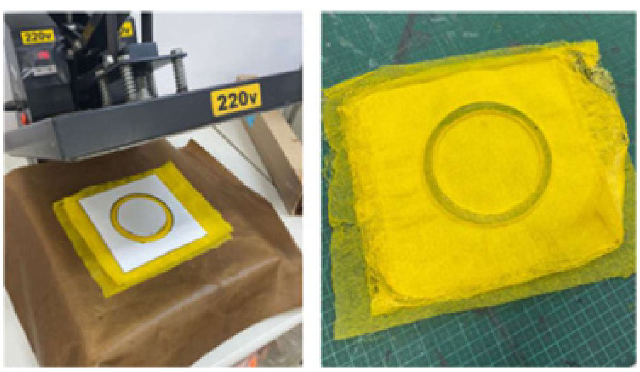

Figure 24: Sublimation press with layers of TNT, fleece, and MDF assembled (left) and the pressed result (right).
Source: The authors.

Both the mold and press surfaces require non-stick coatings to prevent molten SMS material from adhering, particularly to porous mold surfaces. In the experimental setup, Teflon foil was applied to both the upper and lower press surfaces, while the molds were lined with repurposed adhesive insulating material - a readily available resource in PUC-Rio's printing workshop. Alternative non-stick solutions like wax and oils were also evaluated, though their effectiveness proved dependent on multiple factors including application thickness, operating temperature, and the base material's porosity.

Simple components require relatively straightforward molds, needing only properly stacked SMS layers in the appropriate configuration (Figure 24). More complex parts may demand multiple pressing cycles. For the mask prototype, two pressings proved sufficient: the first creates the filtered layer with edge seals, while the second joins the upper and lower sections to complete assembly.

The filters were specifically designed for compatibility with an additively manufactured mask model featuring an FDM-printed TPE shell and ABS front rim. This integrated design approach allows for complete local production of both mask and filter components (Figure 25), representing a promising direction for ongoing research and development.

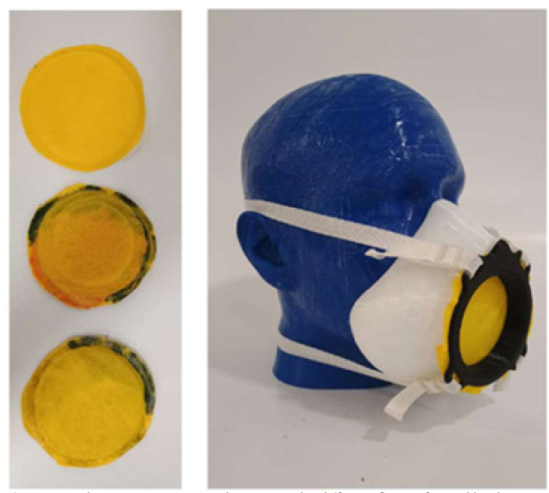

Figure 25: Three tests were carried out using the different fleeces formed by the cotton candy machine (left). On the right the A01V16 mask with the integrated concept filter.
Source: The authors.

7. CONCLUSION

The adaptation of cotton candy machine principles for respiratory mask filter production represents an innovative approach to address the increasing demand for protective equipment. This method enables the creation of electrostatically charged polymeric fibrous membranes, allowing rapid scaling of filter manufacturing during public health emergencies (Wibisono et al., 2020). As demonstrated during the

COVID-19 pandemic, this unconventional technique offers both cost efficiency and manufacturing flexibility in crisis situations (Wibisono et al., 2020).

Building on this concept, the current study presents a further simplified device design for mask filter production, potentially offering a more accessible and economical alternative to conventional methods that requires no specialized expertise. Through strategic repurposing and functional redesign of standard tools, this research aims to advance both technological accessibility and safety standards in personal protective equipment.

The adapted machine developed for prototyping and research applications demonstrates potential beyond filter manufacturing, serving as an effective plastic-to-fiber recycling system. This technique holds particular promise for the design and fashion industries, where it could transform recycled plastics into raw fibrous material suitable for producing textiles, cushioning, and foam products.

The combined use of the modified cotton candy machine and sublimation hot press for filter production highlights the innovative approaches required to mitigate supply chain vulnerabilities in critical protective equipment. This methodology, which repurposes existing tools and develops alternative manufacturing processes, enables decentralized production facilities to supplement traditional filtration element manufacturing. Such solutions prove particularly valuable when addressing global challenges like the recent pandemic. While further refinements are necessary, current research continues to optimize and simplify the filter media production process.

8. FUTURE WORK

Building upon published studies demonstrating the feasibility of producing mask filters with commercial-grade quality and safety standards - particularly Bandi (2020) and Molina (2020) - this research outlines four key development areas:

1. Production Process Optimization: Refine the cotton candy-inspired plastic casting method to establish optimal parameters including material selection, melting temperatures (160-200°C range), extrusion speeds (3000-15000 rpm), and fiber diameter control (targeting 0.5-5µm), while implementing electrostatic charging protocols from literature.
2. Material Characterization: Conduct comprehensive analysis of fiber morphology using SEM imaging, diameter distribution via laser diffraction, and spatial arrangement within the filter matrix.
3. Performance Validation: Evaluate filtration efficiency against NIOSH standards, measuring both particulate retention (for 0.3µm particles) and airflow resistance (<350 Pa at 85L/min).
4. Economic Assessment: Compare production costs against conventional methods, analyzing scalability potential for decentralized manufacturing using repurposed tools, with particular focus on sustainability metrics.

This integrated approach aims to develop a novel filter manufacturing methodology that combines accessible tools with optimized processes to achieve scalable, cost-effective production without compromising performance standards.

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