ELSEVIER

Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.

Materials Today: Proceedings 59 (2022) 756–763

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

The feasibility of masks and face shields designed by 3D printing makers; some considerations of their use against the COVID-19

R.S. Monzamodeth [a,b,*], N.I. Román-Roldán [c], B. Hernández-Morales [a], I. Puente [a], O. Flores [a,b], F. Castillo [b], B. Campillo [a,b]

[a] Facultad de Química, Universidad Nacional Autónoma de México, CP 04510 Ciudad de México, Mexico
[b] Instituto de Ciencias Físicas, Universidad Nacional Autónoma de México, CP 62210 Cuernavaca Morelos, Mexico
[c] Instituto de Energías Renovables, Universidad Nacional Autónoma de México, CP 62580 Temixco Morelos, Mexico

ARTICLE INFO

Article history:
Available online 31 December 2021

Keywords:
3D printing
CFD analysis
Copper membranes
Mask-makers
Face shield
COVID-19

ABSTRACT

The use of mask and face shield has been established as one of the main preventive measures for the control of COVID 19 spread. In Mexico, as well as in other regions of the world, 3D printing has been employed for the design and production of masks and face shields as personal protective equipment (PPE). These models have been fabricated mainly by the makers, industries, and university communities; therefore, it is necessary to analyze the feasibility of the 3D printed PPE to understand its advantages and limitations. In this work, some characteristics of masks and face shields fabricated by additive manufacturing were studied to explore their viability as protection against flow fluids similar to human sneeze. In the present paper, the PPE was designed, and 3D printed utilizing three types of polylactic acid (PLA) as base material. The morphology and the surface elemental analyses of sectioned samples were analyzed by scanning electron microscopy (SEM) and energy dispersion x-ray spectroscopy (EDS). Showing spacing between printed layers, porous areas, and dispersed copper particles. On the other hand, a computational fluid dynamics (CFD) simulation was carried out, the results demonstrated the importance of using PPE for protection of a possible exposure to a "contaminated" aerosol and human sneeze. Based on the above-mentioned results, it is possible to consider the commercial PLA as suitable material for the manufacturing of PPE due to its capability to be disinfected employing isopropanol, ethanol, or commercial disinfectants.
Copyright © 2022 Elsevier Ltd. All rights reserved.
Selection and peer-review under responsibility of the scientific committee of the Third International Conference on Recent Advances in Materials and Manufacturing 2021.

1. Introduction

The COVID 19 disease has affected a large part of the countries of the world, to the point that on March 2020 was classified by the world health organization (WHO) as a pandemic. The serious complications associated with the disease include pneumonia, mainly in adults; the population that is at higher risk is composed of those who suffer chronic diseases such as diabetes, hypertension, and obesity [1,2]. Because the spread of COVID 19 can occur from direct contact with surfaces and through particles in the air, a prompt response was necessary to counteract the pandemic [1–4]. This added to the complexity of identifying asymptomatic and pre-asymptomatic persons through large-scale tests [2]. Consequently, the new disease has caused a worldwide shortage of personal protective equipment (PPE) [1–9], mainly for healthcare professionals. Several work teams around the world have developed PPE using additive manufacturing technology, having significant contributions in the fabrication of masks, face shields, swabs for PCR analysis, ventilators, door holders, respiratory valves, among other components for medical applications [2–8]. The advantage that 3D printing has shown for supporting healthcare professionals is based on its capability to manufacture prototypes and functional equipment in a very short time. The global industrial, university and "makers" community has shared several open-source designs [1–8]. The most employed material for 3D printing is polylactic acid (PLA), which is a low-cost, commercially available, and relatively biodegradable polymer. It has been implemented for various applications such as engineering, medical, recreational areas, among others [10–14]. PLA has adequate mechanical properties

* Corresponding author.
E-mail address: amrsroman@icf.unam.mx (R.S. Monzamodeth).

https://doi.org/10.1016/j.matpr.2021.12.503
2214-7853/Copyright © 2022 Elsevier Ltd. All rights reserved.
Selection and peer-review under responsibility of the scientific committee of the Third International Conference on Recent Advances in Materials and Manufacturing 2021.

to develop prototypes or components that do not required high strength demand. Furthermore, considering some important features of PLA for continuous use, such as filtering, cleaning, and low allergenic skin response, it can be employed for medical purposes. The viability of PLA to produce masks and face shields has been reported, it is not permeable to sub-microscopic particles; in addition, it can be commonly disinfected using ethanol, isopropanol, or commercial disinfectants [1,4]. In the present work, masks and face shields were design and manufactured by 3D printing, introducing modifications to the original mask design and its performance. Besides, morphology analysis and an elemental mapping were carried out by scanning electron microscopy (SEM) and energy dispersive x-ray spectroscopy (EDS), respectively. On the other hand, a model was computed utilizing computational fluids dynamics (CFD) to demonstrate the importance of using face shields and masks. Throughout this hard current situation, this research team has supported nearby clinics with PPE and by communicating the correct use of 3D printed equipment, as well as its limitations.

2. Material and methods

A general process of the present work that includes the design and manufacture of the masks and face shields, the material characterization and fluid flow simulation by CFD is shown in Fig. 1. Starting with the CAD design of the masks and face shields followed by the 3D printing, using three different PLA types. Subsequently, samples were sectioned from the manufactured PPE to analyze the surface morphology of the PLA by SEM, as well as its elemental constituents by EDS.

2.1. CAD design and 3D printing

The masks and face shields were designed by CAD software, the "STereoLithography" (STL) formats were obtained and finally G-code was developed employing open-source software. The manufacturing of the 3D printing designs was performed with low-cost commercially available 3D printer equipment and three different types of PLA were used: PLA-Copper, PLA-Wood and PLA-Standard; the 3D printing parameters are shown in Table 1. Fig. 2a shows the modified mask design based in the NanoHack Copper3D initiative [15]. On the other hand, commercial acetate

Table 1
3D printing parameters.

Nozzle temperature	Nozzle diameter	Hot bed temperature	Printing velocity
195 ± 3 [°C]	0.4 [mm]	55 ± 2 [°C]	50 [mm/s]

was employed for the design of the face shield, the dimensions are as follows: 200 mm × 200 mm × 1 mm for the width, length, and thickness, respectively, the details are shown in Fig. 2b.

Regarding the breathing valve of the mask, it was cancelled due to several world recommended suggestions. However, the "threaded plug" (TP) designed was preserved and instead commercially available copper membranes (CM) and conventional filters (CF) were placed in the resulting space, as shown in Fig. 3. Copper can provide additional protection to the filters because eliminate pathogenic organisms such as coronavirus [16] in less time compared with other materials including steels, cloth, and plastics [17–20].

2.2. CFD model

The geometric model was imported and generated in ANSYS DesignModeler with a compatible extension. An enclosure was generated to cover and simulate the external conditions which assist to define the boundary conditions (see Fig. 4a). The dimensions of the mask structure considered two main values, one in front-structure contact with 150 mm long and the other structure-acetate with 208 mm long, both having a thickness of 10 mm and separated by 40 mm between themselves. Furthermore, the mask has a width of 147 mm, a length of 197 mm and a thickness of 1 mm.

2.2.1. Mesh generation

Meshing is a fundamental part of the simulation process to solve the Navier-Stokes equations which model fluid dynamics. The geometric model (domain) was divided into elements, creating an unstructured mesh. According to the shape of the geometrical model described above, the type of element that best adapts to the mask was the tetrahedron. The mesh was fabricated with ANSYS Mesh tools, applying an element size refinement of 0.004 m to meet mesh quality requirements. The resulting mesh

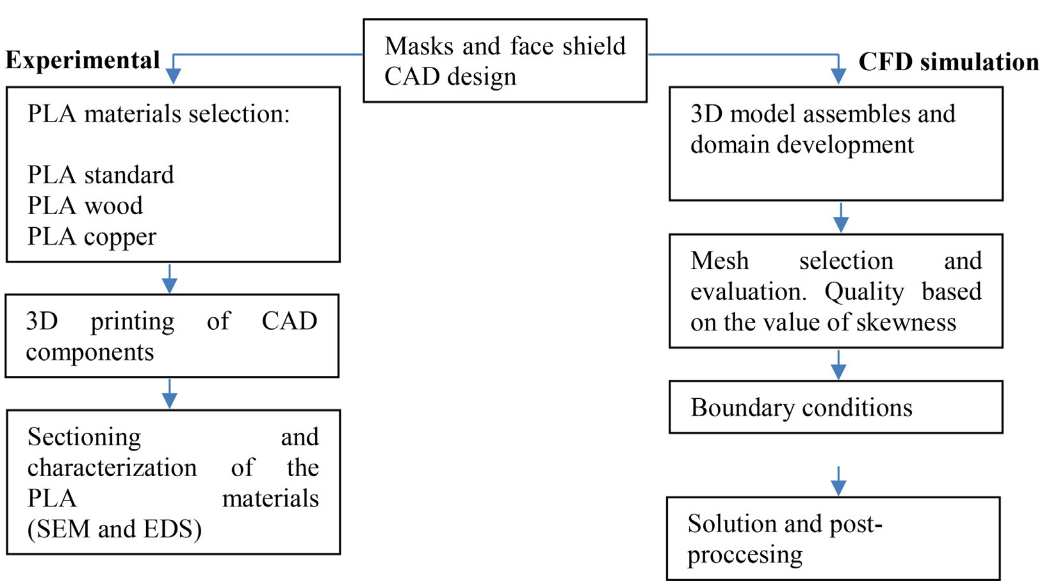

Fig 1. Flow diagram of the experimental and CFD simulation.

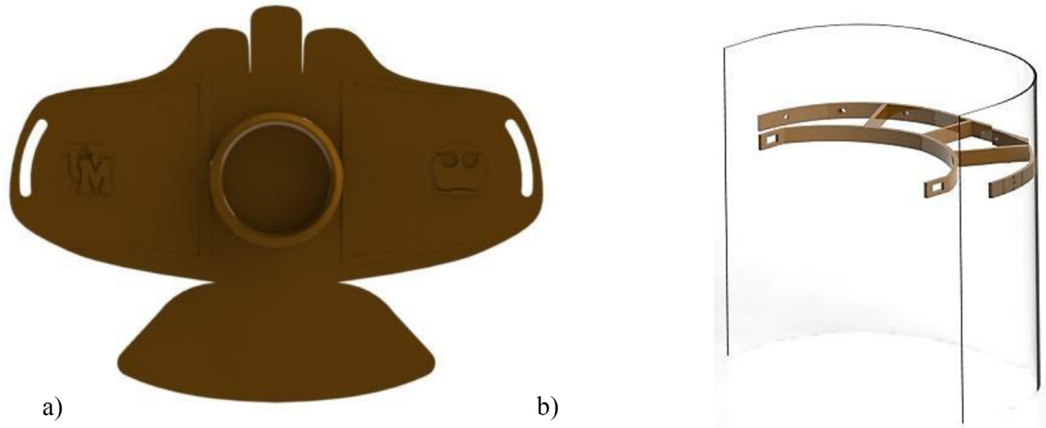

Fig 2. Designed models a) Modified mask (top view) and b) Face shield.

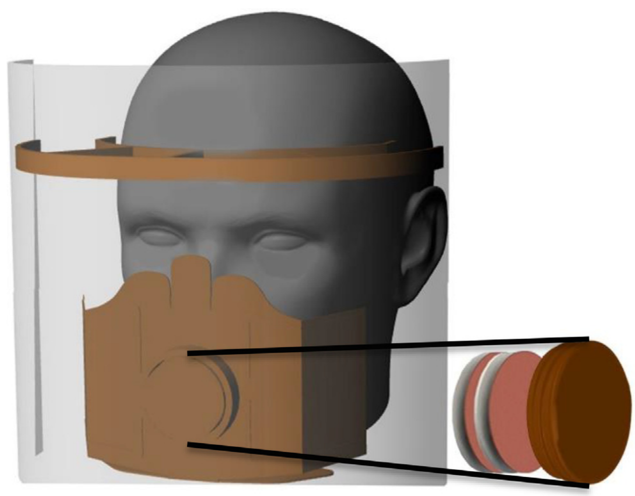

Fig 3. Mask and face shield assembly on head model. The projection of the internal arrangement between the mask and threaded plug is shown.

is comprised of 6.5 million elements with a bias mesh metric of 2.6831e-09 minimum and 0.9712 maximum, which meets minimum mesh quality requirements. These values reduce computation time and provide adequate results. The computed systems were head-mask (HM), head-face shield (HF) and head-mask-face shield (HMF). Mesh details are presented in Fig. 4b.

2.2.1.1. Boundary conditions. The geometric model contained the mask and face shield placed on a human head. In this study, boundary conditions previously described in the literature [21–24] were applied. The flow direction of ambient air (at constant temperature) is perpendicular to the mask. In this case study, it was considered a frontal exposure of the model to a human sneeze with a velocity of 10 m/s, also, a hypothetical uniform distribution of the fluid. The conditions are shown schematically in Fig. 5 and the actual values are listed in Table 2. It was assumed that the inlet air velocity is equally distributed throughout the area.

2.2.1.2. Mathematical model. The mathematical model was based in equations considering 3D, steady state, incompressible fluid, isothermal conditions, and laminar flow; the average speed of a human sneeze [21–24] was also incorporated in the boundary conditions. Thus, fluid flow can be modeled by the momentum conservation and the mass conservation equations, Eq.1 and Eq.2, respectively:

$$\rho \frac{du}{dt} = -\nabla p + \mu \nabla^2 u + \rho g \tag{1}$$

$$\frac{d\rho}{dt} + \rho \nabla \cdot u = 0 \tag{2}$$

where ρ: fluid density; u: fluid velocity; p: static pressure; ρg: gravitational body force; μ: dynamic viscosity of fluid [25].

2.3. SEM and EDS analysis

Mask samples were taken to perform morphological analysis of the different printed materials and to observe the structure of the material after it was manufactured. EDS elemental mapping was carried out to observe possible copper particles, the equipment

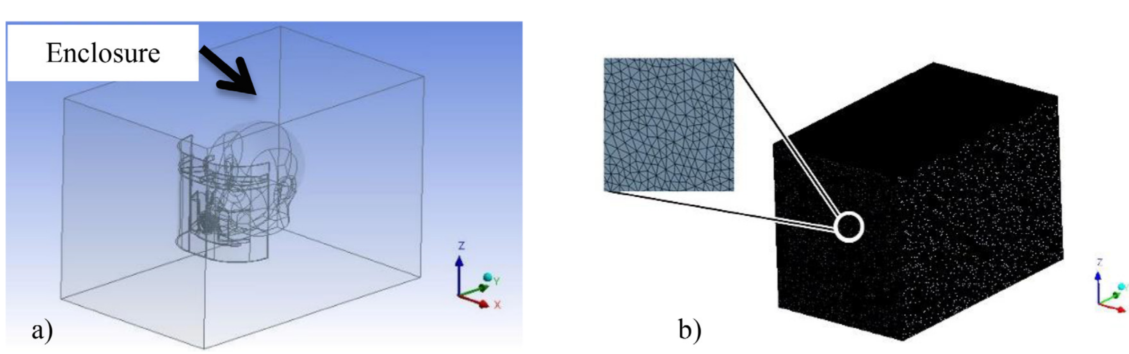

Fig 4. Geometric model characteristics a) Enclosure and b) Mesh generated.

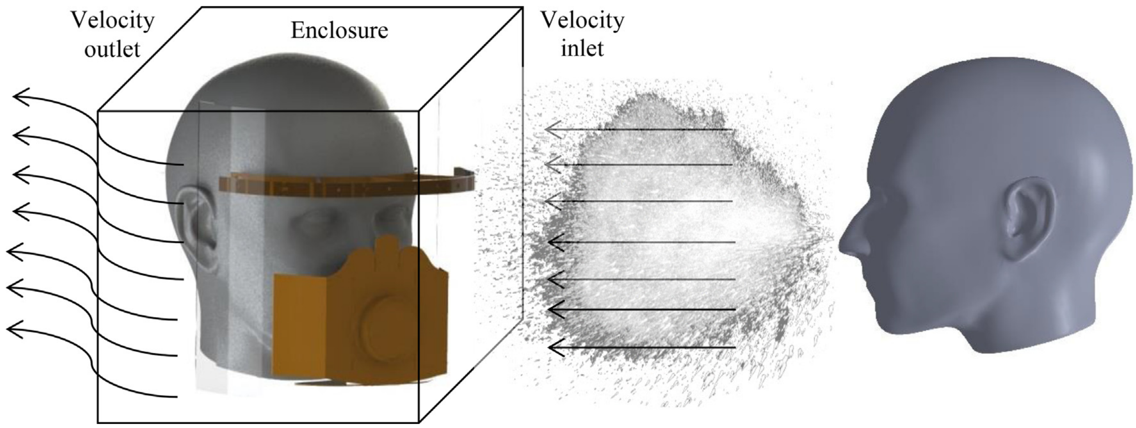

Fig 5. Geometric model of mask-face shield protection and boundary conditions.

Table 2
Boundary conditions.

Surface	Boundary conditions	Value
Inlet	Velocity inlet	10 [m/s] [21–24]
Outlet	Pressure Outlet	0 [Pa]

used was a SEM JEOL, 5900 LV coupled with an Inca Oxford EDS detector.

3. Results

3.1. Masks and face shields

The masks and face shields were fabricated implementing the manufacturing parameters as mentioned in the CAD design and 3D printing section. The printed designs are shown in Fig. 6a and 6b; these were used for their subsequent SEM-EDS characterization. The manufactured items were molded using human face models (see Fig. 6c); this process was carried out using hot air at ~60 °C as a constant temperature.

3.2. CFD results

As mentioned in the CFD model section, a simulation was performed to demonstrate the efficiency of masks and face shields against the flow caused by a human sneeze. Although the model had many assumptions (isothermal, steady state, and laminar flow conditions) it is considered to be useful in demonstrating the effectiveness offered by this type of protection (in general, not necessarily 3D printed PPE). In Fig. 7a, 7b and 7c the HM, HF and HMF systems are presented. The zone in red represents fluid flow without significant interaction with the solids (keeping its speed constant). The other colors represent the interaction of the air with the solids; it is possible to observe that the mask fulfills its protective function with respect to the mouth and nose; however, the eyes are exposed to the potentially contaminated fluid. Fig. 7b

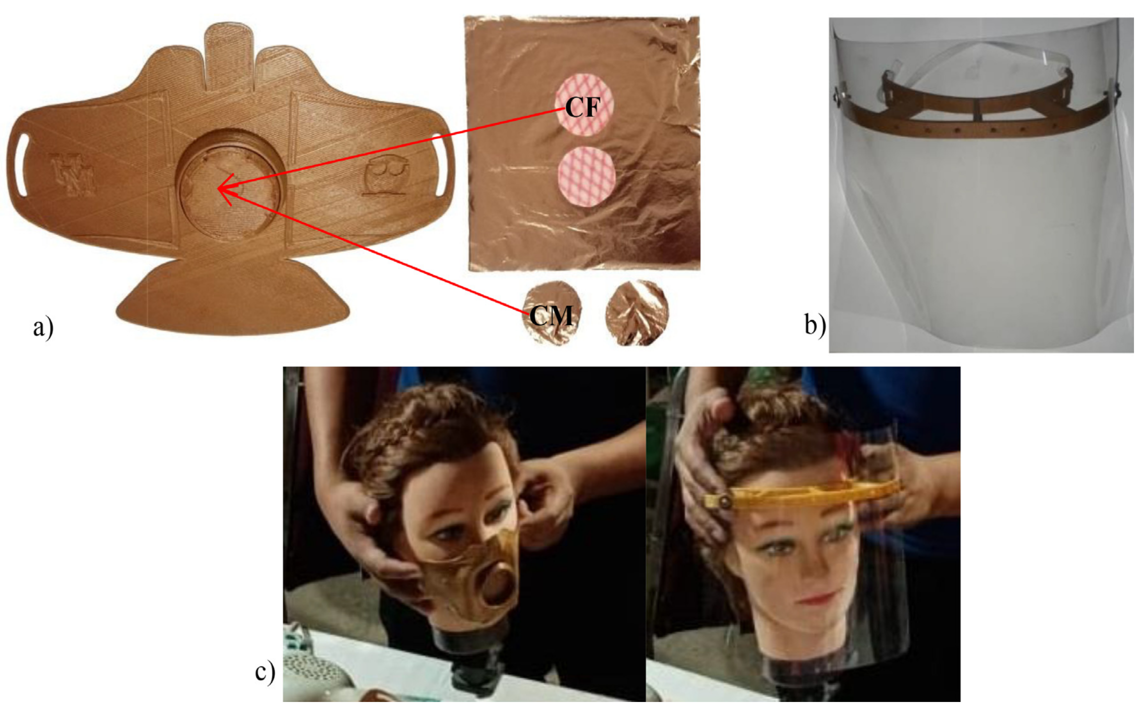

Fig 6. 3D printed Models a) Mask, showing the CF and CM, b) Face shield and c) Mask and face shield molded.

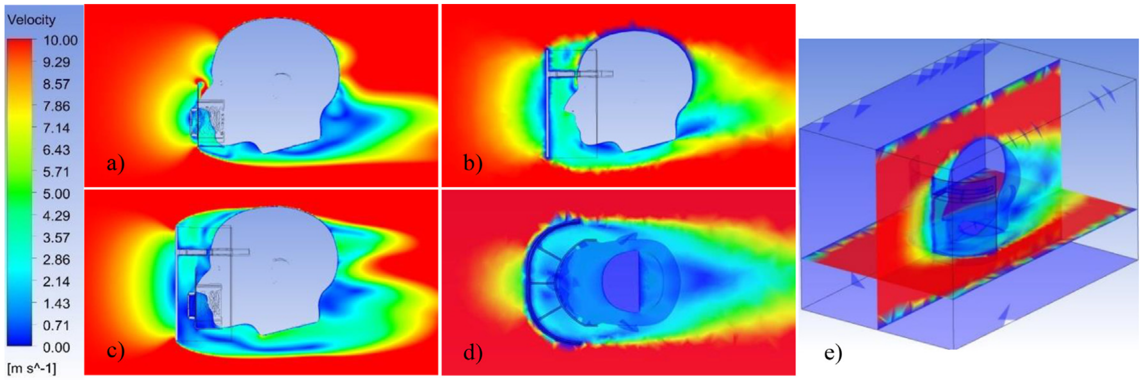

Fig 7. Results of the CFD simulation for the systems a) HM, b) HF, c) HMF, d) Bottom view of HF and e) Isometric view of HF.

and 7c show the wide protection of the face shield, it is possible to suggest its use at crowded places. The protection provided by the face shield is more efficient because it covers the entire face. In Fig. 7d a bottom view of the face shield is shown; fluid flow can be seen surrounding the model. Finally, in Fig. 7e two fluid flow planes are shown in an isometric view, demonstrating the extensive protection provided by the modified design. The former results suggest that the use of the PLA-Copper mask added with filters with copper membranes could be considered as a good protection against the frontal fluid of a human sneeze. However, due to the behavior of the fluid, it may be possible that viruses and bacteria get trapped in the filters and nearby regions. The mask designed could provide a better protection due to the use of copper, decreasing the active time of the virus due to the inhibit action of copper [16]. In this case, the SARS-CoV-2 that managed to get trapped in the copper membranes and PLA-Copper regions could be inactivated in less time than the home-made masks or those made with common materials [17–20]. The main idea of the preceding inhibition is illustrated in Fig. 8, it is evident that this a hypothesis of the great advantage of using membranes and PLA added with copper.

3.3. Morphology analysis by SEM

The SEM analyses for different printed materials are shown in Fig. 9; it can be observed the internal structure of the printed designs, showing the separation between printed layers, porous areas, and dispersed particles in the three PLA materials (indicated with arrows). In the case of PLA-Copper (see Fig. 9a and 9d), a uniform printed product is observed, that is, the spacing between layers has good quality interlayer which helps to avoid porosity. In Fig. 9b and 9e corresponds to the PLA-Wood, this material appears to contain porosity on its surface and lower quality of spacing and surface finish compared with the PLA-Copper. Finally, PLA-Standard material is shown in Fig. 9c and 9f, it has a greater spacing between layers than the others printed materials which represents a decrease in interlayer quality. Despite the layers spacing, the filtering capacity can be more efficient than home-made fabric masks since these contain a wide pore distribution [26].

3.4. Elemental mapping

Since the PLA is composed by $(C_3H_4O_2)_n$ it was expected that the EDS analysis show the carbon and oxygen elements. In addition to the above mentioned, small concentrations of other elements were expected because the PLA-Copper and PLA-Wood materials were also used. In Fig. 10a the EDS analysis corresponding to PLA-Copper shows the copper concentration. The amount of copper detected was low; however, it is very helpful against SARS-CoV-2 since it can inhibit the virus in less time compared to materials such as steels, polymers, cloth, among others [16–19]. On the other hand, in Fig. 10b and 10c the mappings corresponding to PLA-Wood and PLA-Standard are presented. In both cases, silicon particles are observed, this may be due to contamination during handling of the manufacturing surface or the presence of dust.

The present work shows the viability of 3D printed mask and face shields for daily use as a means of protection against the spread of COVID 19. Several published works reported various types of masks and face shields as immediate response to the current emergency [2–8]. Some of the reports mention advantages that are mentioned below. The implementation of this type of masks and face shields can be produce with the possible versatile manufacture of customized PPE [1–8]. The ease of being 3D printing by engineers and non-expertise in the area is an advantage this type of technology [10–14], also, their low cost in relation to their long lifetime. Additionally, the possibility of 3D printed masks to be cleaned using simple methods such as the application of isopropanol [1,4]. It is important to mention some characteristics and projections on the mask, these mainly lie in its ability to be reusable, and it can be use intensively through daily application of disinfectants. Also, the use of PLA-Copper as base material and filters with copper membranes can offer additional protection to the user as this element is capable to inactive the virus in less time than conventional mask-making materials [16–20]. However, a disadvantage considered lies in the 3D printing time of each PPE, which makes the mass production of PPE impossible. In addition, the effect of long-time exposure of the material to human skin must be carefully analyzed. In general, the current pandemic due to COVID 19 is still a delicate issue due to the new strains of the virus that have been reported in several countries and because of the need for daily work in many sectors of the world population. In México, ~3.9 million confirmed cases, ~2.3 million people recovered and unfortunately ~284 thousand deaths have been reported up to 10/17/2021 (see Fig. 11) [27]. The employ of 3D printed personal protective equipment has been widely discussed by several authors, agreeing that the use of masks and face shields is essential to reduce the virus spread [1–8]. Also, some other works suggest supply medical grade masks for the general population due to their greater filtering efficiency.

Recently, the United Kingdom's prime minister reported a new variant found in London, which may be associated with higher mortality. Therefore, health safety measures should not be lowered since this virus can mutate and be more contagious or deadly [28]. In this work, the use of masks and face shields is always recommended outside the home since it is the second-best protection, being confinement the first one. Regarding the masks and face shields reported in this work, several PPE have been donated to

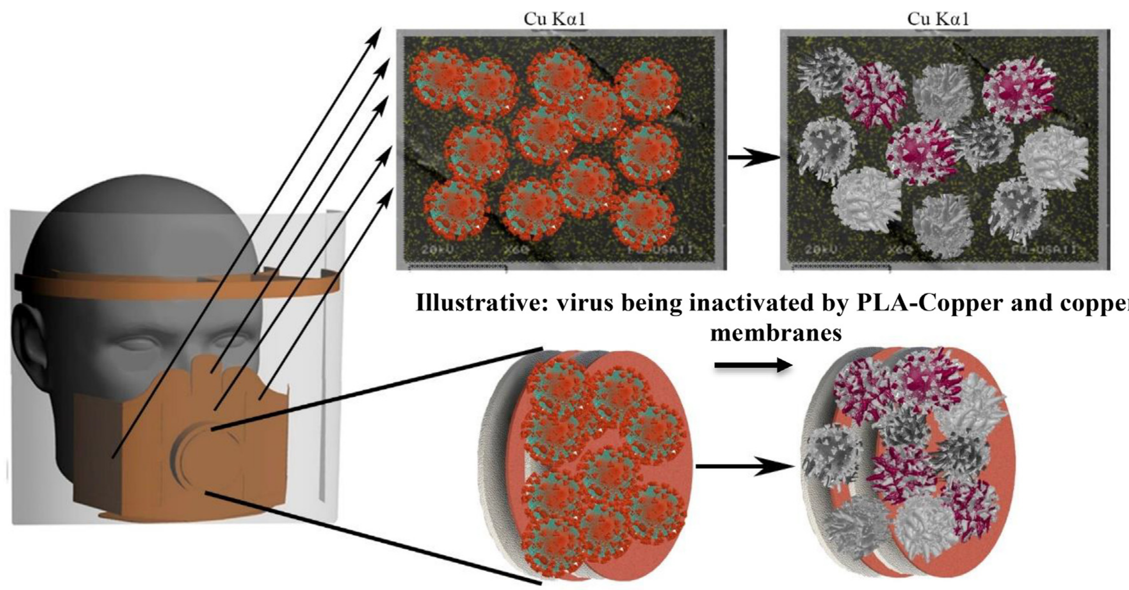

Fig 8. Illustrative figure of the possible inhibit action of the SARS-CoV-2 virus through the use of masks and face shields added with copper membranes and manufactured using PLA-Copper.

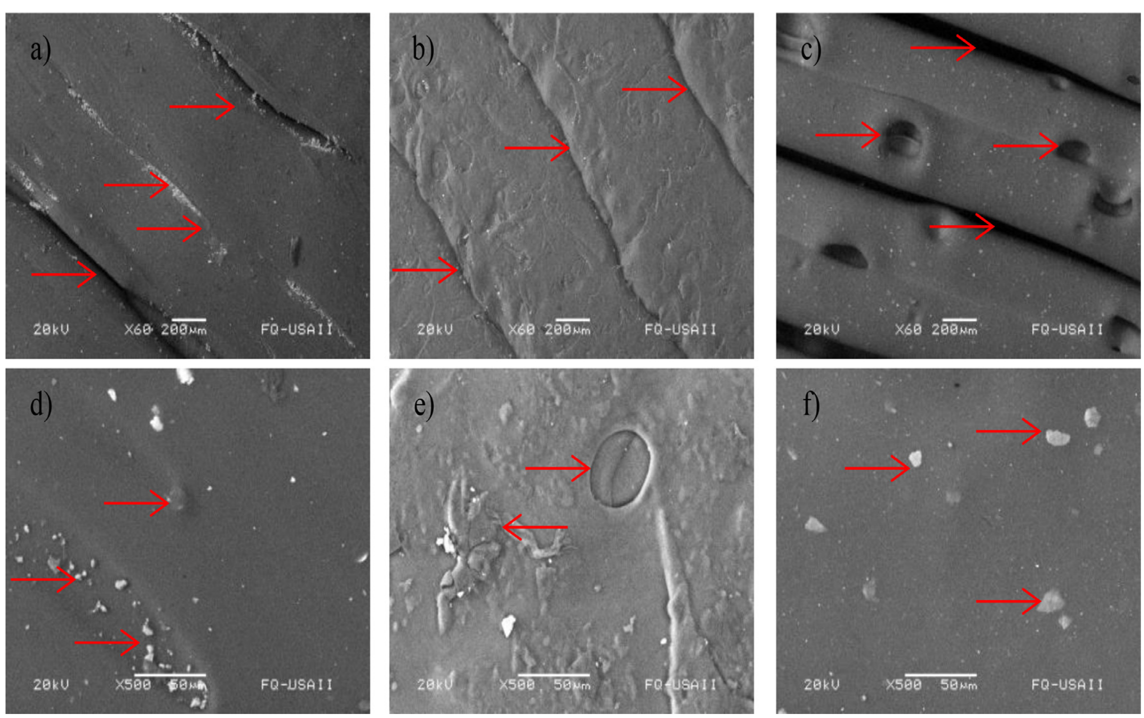

Fig 9. Morphological analysis of 3D printed designs at two different magnifications a, d) PLA-Copper, b, e) PLA-Wood and c, f) PLA-Standard.

healthcare professionals and to the general population (see Fig. 12). The recommendations for using the 3D printed personal protective equipment lie in its use combined with masks of different filters such as KN95, constant sanitization and filter change.

4. Conclusions

The feasibility of the use of masks and face shields for personal protective equipment (PPE) against COVID 19 was studied. Masks were designed based in the NanoHack Copper3D initiative, modifying the design, cancelling the breathing valve, and placing additional filters with copper membranes. In addition, face shields were also manufactured to complement the PPE. Morphology and elemental analyses by SEM/EDS were carried out, it was confirmed the presence of copper in the PLA-Copper. On the other hand, the CFD model computed, considering air flowing at a human sneeze speed, was able to demonstrate the protection provided by the 3D printed PPE. It was possible to contribute to the medical community functional masks and face shields, whose main advantage is the use of copper either in the base materials or filters. Furthermore, the use of PLA-Copper and copper-added membranes represent a boost for the inhibition of the virus. The proposed

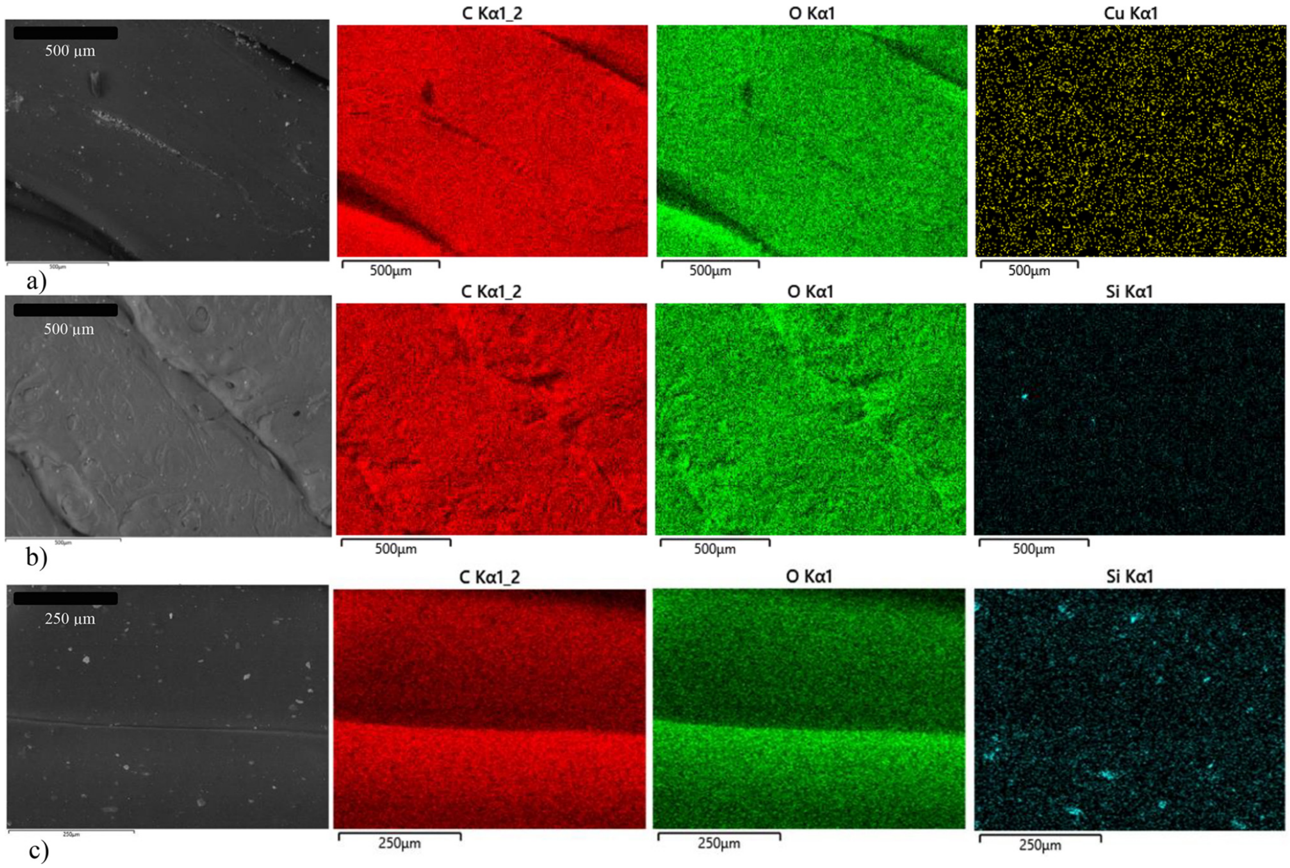

Fig 10. Elemental mapping a) PLA-Copper, b) PLA-Wood and c) PLA-Standard.

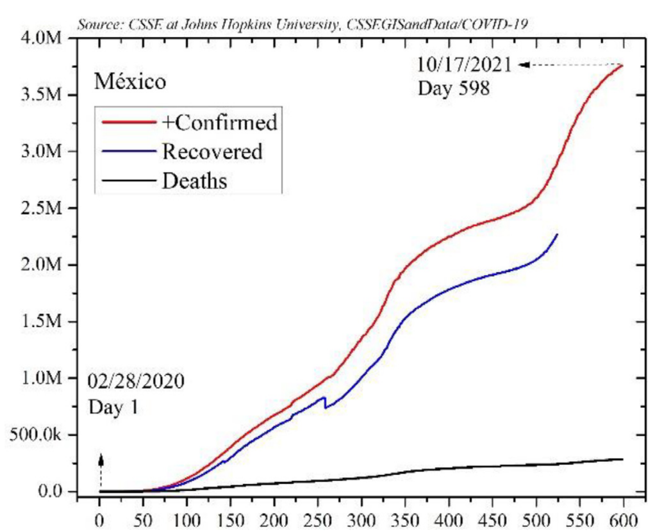

Fig 11. Evolution of confirmed cases (red line) recovered cases (blue line) and deaths (black line) in Mexico (02/28/2020 to 10/17/2021). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

design can be considered similar in operation with the basic designs reported by various authors; however, the advantage lies in the use of copper as a base material and added to an extra compartment, the latter replace the common valve. These characteristics are very important for medical personnel who are in direct contact with asymptomatic, pre-asymptomatic and confirmed COVID 19 patients.

CRediT authorship contribution statement

R.S. Monzamodeth: Conceptualization, Methodology, Software, Investigation, Writing – original draft, Writing – review & editing, Formal analysis. **N.I. Román-Roldán:** Conceptualization, Methodology, Software, Formal analysis, Resources. **B. Hernández-Morales:** Validation, Formal analysis, Writing – review & editing, Visualization, Supervision. **I. Puente:** Validation, Formal analysis, Visualization. **O. Flores:** Methodology, Validation, Formal analysis, Investigation, Writing – review & editing, Supervision. **F. Castillo:** Methodology, Validation, Formal analysis, Investigation, Writing – review & editing, Supervision. **B. Campillo:** Validation, Formal analysis, Resources, Writing – review & editing, Visualization, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

R.S. Monzamodeth acknowledges the PhD scholarship support from CONACYT (CVU: 828336) and the technical support of H. H. Hinojosa Galvan, and E. Vázquez from ICF-UNAM and G. Aramburo, S. García, and I. Reyes from FQ-UNAM. Also, to the Papitt-UNAM project IT 102619.

Fig 12. Masks and face shields donated to healthcare professionals.

References

[1] B.I. Oladapo, S.O. Ismail, T.D. Afolalu, D.B. Olawade, M. Zahedi, Review on 3D printing: fight against COVID-19, Mater. Chem. Phys. 258 (2021) 123943.

[2] M.A. Fernández-Rojas, M.A. Luna-Ruiz Esparza, A. Campos-Romero, D.Y. Calva-Espinosa, J.L. Moreno-Camacho, A.P. Langle-Martínez, A. García-Gil, C.J. Solís-González, A. Canizalez-Román, N. León-Sicairos, J. Alcántar-Fernández, Epidemiology of COVID-19 in Mexico, symptomatic profiles and presymptomatic people, Int. J. Infect. Diseases 104 (2021) 572–579.

[3] R. Tino, R. Moore, S. Antoline, P. Ravi, N. Wake, C.N. Ionita, J.M. Morris, S.J. Decker, A. Sheikh, F.J. Rybicki, L.L. Chepelev, COVID-19 and the role of 3D printing in medicine. 3D Print. Med. 6 (2020) 11.

[4] E. Vaňková, P. Kašparová, J. Khun, A. Machková, J. Julák, M. Sláma, J. Hodek, L. Ulrychová, J. Weber, K. Obrová, K. Kosulin, T. Lion, V. Scholtz, Polylactic acid as a suitable material for 3D printing of protective masks in times of COVID-19 pandemic, PeerJ 8 (2020) e10259.

[5] S. Belhouideg, Impact of 3D printed medical equipment on the management of the Covid19 pandemic, Int. J. Health Plan. Manage. 35 (2020) 1014.

[6] M. Tarfaoui, M. Nachtane, I. Goda, Y. Qureshi, H. Benyahia, 3D printing to support the shortage in personal protective equipment caused by COVID-19 pandemic, Materials 13 (2020) 3339.

[7] M.I. Haq, K.S. Ul, A. Raina, S. Khajuria, M. Javaid, M.F. Haq, H.A. Ul, 3D printing for development of medical equipment amidst coronavirus (COVID-19) pandemic—review and advancements, Res. Biomed. Eng. (2020).

[8] P.R. Armijo, N.W. Markin, S. Nguyen, D.H. Ho, T.S. Horseman, S.J. Lisco, A.M. Schiller, 3D printing of face shields to meet the immediate need for PPE in an anesthesiology department during the COVID-19 pandemic, Am. J. Infect. Control 49 (3) (2021) 302–308.

[9] C.M. Dugdale, R.P. Walensky, Filtration efficiency, effectiveness, and availability of N95 face masks for COVID-19 prevention, JAMA Int. Med. 180 (2020) 1612.

[10] S. Guessasma, S. Belhabib, A. Altin, On the tensile behaviour of bio-sourced 3D-printed structures from a microstructural perspective, Polymers. 12 (2020) 1060.

[11] C. Eyholzer, P. Tingaut, T. Zimmermann, K. Oksman, Dispersion and reinforcing potential of carboxymethylated nanofibrillated cellulose powders modified with 1-hexanol in extruded poly(lactic acid) (PLA) composites, J. Polym. Environ. 20 (2012) 1052.

[12] N. Li, Y. Li, S. Liu, Rapid prototyping of continuous carbon fiber reinforced polylacticacid composites by 3D printing, J. Mater. Process. Technol. 238 (2016) 218.

[13] A. Beltagui, N. Kunz, S. Gold, The role of 3D printing and open design on adoption of socially sustainable supply chain innovation, Int. J. Prod. Econ. 221 (2020) 107462.

[14] M. Gebler, J.M. Anton, S. Uiterkamp, C. Visser, A global sustainability perspective on 3D printing technologies, Energy Policy. 74 (2014) 158.

[15] https://copper3d.com; consulted: 25/04/2021

[16] H.T. Michels, EPA officially says copper surfaces help fight COVID-19, Adv. Mater. Processes (2021) 27.

[17] N. Doremalen Van, T. Bushmaker, D.H. Morris, M.G. Holbrook, A. Gamble, B.N. Williamson, A. Tamin, J.L. Harcourt, N.J. Thornburg, S.I. Gerber, J.O. Lloyd-Smith, E. de Wit, V.J. Munster, Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1, National England Journal of Medicine. 382 (2020) 1564.

[18] R. Vazquez-Munoz, J.L. Lopez-Ribot, Nanotechnology as an Alternative to Reduce the Spread of COVID-19, Challenges. 11 (2020) 15.

[19] Z. Sun, K. Ostrikov, Future antiviral surfaces: lessons from COVID-19 pandemic, Sustain. Mater. Technol. 25 (2020) e00203, https://doi.org/10.1016/j.susmat.2020.e00203.

[20] A.A. Cortes, J.M. Zuñiga, The use of copper to help prevent transmission of SARS coronavirus and influenza viruses. A general review, Diagn. Microbiol. Infect. Dis. 98 (2020) 115176.

[21] R. Mittal, R. Ni, J.H. Seo, The flow physics of COVID-19, J. Fluid Mech. 894 (2020) F2–F11.

[22] P. Bahl, C. M. de Silva, A.A. Chughtai, C.R. MacIntyre, C. Doolan, An experimental framework to capture the flow dynamics of droplets expelled by a sneeze, Experiments Fluids 61 (2020) 176.

[23] M.R. Pendar, J.C. Pascoa, Numerical modelling of the distribution of virus carrying saliva droplets during sneeze and cough, Physics Fluids 32 (2020) 083305.

[24] H. Nishimura, S. Sakata, A. Kaga, K. Harrod, A new methodology for studying dynamics of aerosol particles in sneeze and cough using a digital high-vision, high-speed video system and vector analyses, PLoS ONE 8 (11) (2013) e80244.

[25] FLUENT 12.1 User's Guide, Fluent Inc. Available online: http://www.afs.enea.it/project/neptunius/docs/fluent; 2018.

[26] O. Aydin, B. Emon, S. Cheng, L. Hong, L.P. Chamorro, M.T.A. Saif, Performance of fabrics for home-made masks against the spread of COVID-19 through droplets: a quantitative mechanistic study, Extreme Mech. Lett. 40 (2020) 100924, https://doi.org/10.1016/j.eml.2020.100924.

[27] CSSE at Johns Hopkins University, CSSEGISandData/COVID-19.

[28] E. Mahase, Covid-19: What new variants are emerging and how are they being investigated?, BMJ 372 (2021)