3D-printable wearable pad for the breast skin treatment: design and printing optimization

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Abstract

This study presents the preliminary results obtained to develop a novel biobased and biocompatible wearable pad by exploiting the flexibility and affordability of the Material Extrusion additive manufacturing process, specifically of the Fused Filament Fabrication technology and the unique multifunctional properties of architected materials. The study specifically focuses on identifying and optimizing the key design parameters of the pad, tailored to the unique characteristics of the newly developed composite material used in its fabrication. The primary objective is to develop a wearable patch designed for direct application on the skin, enabling targeted topical treatment over the covered surface area. Therefore, it must be lightweight, breathable, non-invasive, biocompatible, and ergonomically conformable to the human body -specifically the women's breast, the intended area of treatment-ensuring comfort and minimizing any potential inconvenience. It must be manufactured without asperities to avoid skin irritation due to the potential rubbing of the pad surface over the breast, a sensitive region of the woman's body, in particular after surgical intervention or during breastfeeding. Despite the solutions already available in the literature of 3D-printable patches based on architected materials for wound repair (1), there are no examples of solutions targeted for women's breasts, except some limited and valuable studies, such as the one discussed here (2) presenting a wearable and non-invasive ultrasound breast patch for cancer diagnosis.

The development of the pad is grounded on a complementary study conducted to develop a novel 3D-printable biobased composite material conceived for this scope, which has been obtained by blending a low-extrusion temperature thermoplastic and biocompatible matrix, i.e., the Polycaprolactone (PCL), with biobased content by using a lab-scale extrusion system. The PCL was selected to preserve the biobased content characteristics after the printing. That biobased content is propaedeutically for future research focusing on blending that matrix with a biobased material, which is also bioactive to allow the pad to implement its topical treatment, mainly concerning anti-inflammatory and antioxidant activities. Mechanical characterization was conducted on tensile and compressive samples to thoroughly evaluate the properties of the newly developed material. Simultaneously, the study explored optimal printing parameters to ensure the successful fabrication of a lightweight, deformable, and comfortable-to-wear pad. This included addressing critical factors, such as minimizing

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debris and eliminating stringing within the structure, to achieve a high-quality final product. For the pad design, parametric digital models of auxetic-based configurations have been developed to exploit the synclastic curvature property provided by auxetics. Specifically, preliminary experimental tests have been conducted on a pad exploiting the sinusoidal ligament unit cell because it shows a Poisson Ratio comparable to the skin (3). The final pad design is a sinusoidal "net" conceived to obtain the proper coverage of the breast skin surface that should receive the treatment. Besides, two pad configurations have been designed and printed, one showing a textile-like architecture and a standard planar one. Results show the feasibility of 3D-printing such a lightweight and conformable patch. However, further studies are needed to understand how the pad design and manufacturing parameters influence its mechanical behavior and capability to treat skin properly.

Keywords

Wearable pad, 3D-printing, material extrusion, composite material, mechanical metamaterials

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References

(1) Chansoria, P., Chaudhari, A., Etter, E.L., Bonacquisti, E.E., Heavey, M.K., Le, J., Maruthamuthu, M.K., Kussatz, C.C., Blackwell, J., Jasiewicz, N.E. and Sellers, R.S., 2024. Instantly adhesive and ultra-elastic patches for dynamic organ and wound repair. *Nature Communications*, 15(1), 4720, DOI: 10.1038/s41467-024-48980-0

(2) Du, W., Zhang, L., Suh, E., Lin, D., Marcus, C., Ozkan, L., Ahuja, A., Fernandez, S., Shuvo, I.I., Sadat, D. and Liu, W., 2023. Conformable ultrasound breast patch for deep tissue scanning and imaging. *Science Advances*, *9*(30), eadh5325, DOI: 10.1126/sciadv.adh5325

(3) Chansoria, P., Blackwell, J., Etter, E.L., Bonacquisti, E.E., Jasiewicz, N., Neal, T., Kamal, S.A., Hoque, J., Varghese, S., Egan, T. and Nguyen, J., 2022. Rationally designed anisotropic and auxetic hydrogel patches for adaptation to dynamic organs. Advanced Functional Materials, 32(43), 2207590. DOI: 10.1002/adfm.202207590