The Effect of Orientation Angle of Center Facing Arm on Stretchability of 3D Printed Auxetic Structure Textiles

Shahbaj Kabir, Yu Li, and Young-A Lee, Auburn University, USA

Keywords: 3D printing, auxetic structure textiles, stretchability, textile strength

Introduction and background. The textiles and fashion industry has witnessed an explosion in the use of 3D printing (3DP) technology in recent years due to its simplicity and superior capacity to produce delicate geometries with reduced costs, increased customization, and minimal waste (Anderson, 2017; Biswas et al., 2021; Oladapo et al., 2023). Despite the great potential of 3DP immersing in textiles and fashion industry, 3D printed textiles have a certain gap in terms of flexibility and comfort that need to be overcome for widespread adoption (Wu et al., 2022). Stretchability provides textiles with the ability to accommodate each body movement by stretching to their fullest extent and putting the least amount of pressure on the body which influences wearers' comfort (Shaw & Mukhopadhyay, 2021; Voyce et al., 2005). Furthermore, textiles' stretchability is reflected by the initial region of the load-elongation curve in their tensile evaluation also referred to elastic zone where the textiles behave elastically, the ability to self-reverse once the applied force is removed, under low load (Penava et al., 2020; Shaw & Mukhopadhyay, 2021). The elastic zone is commonly used to analyze textiles' stretchability because the pressure that the body movement places on wearables is equivalent to the pressure that the textile sample experiences in the elastic zone (Penava et al., 2020; Shaw & Mukhopadhyay, 2021).

With continuous research, much progress has been achieved in creating flexible 3D printed textiles with adequate stretchability (Wu et al., 2022; Xiao & Kan, 2022). Auxetic structure is one of the special flexible geometric structures that can offer four-way stretchability to 3D printed textiles (Kabir et al., 2023). The mechanical property of auxetic structure greatly depends on the structural geometry, in particular the orientation of the center facing arms, concave lines that point toward the center or midpoint of the auxetic structure (Shajoo et al., 2021). Consequently, it is assumed that stretchability of 3D printed auxetic structure textiles also relies on the orientation angle of the center facing arm, an angle between the center facing arm and extended side of the auxetic structure. While previous studies explored the potential of using auxetic structures in 3D printed textile development (Kabir et al., 2023; Spahiu et al., 2020; Yang et al., 2018), no research was identified to examine how the orientation angle of center facing arms influence their stretchability. Therefore, this study aimed to examine the effect of the orientation angle of center facing arms on stretchability of 3D printed auxetic structure textiles.

Method. An experimental research design, 6 (auxetic structure textiles) x 3 (repetition), was employed in this study. Previous research by Kabir et al. (2023) demonstrated the potential for multi-angular 3D printed auxetic structure textiles including floral and re-entrant structures to be used for developing wearables with sufficient wearability. These structures were adapted and modified for this experiment. Six auxetic structure textile samples, including one floral-based with orientation angles of 100º, 105º, and 110º, and one re-entrant structure with orientation angles of 25º, 30º, and 35º of the center facing arm, were purposefully selected and fabricated using a commercial fused deposition modeling (FDM) 3D printer with flexible thermoplastic

© 2024 The author(s). Published under a Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

polyurethane (TPU) filament. Each sample has an identical size of 7” x 3” with an equal unit size (0.6” for a diagonal distance), yet each has a different orientation angle. Followed by the ISO 13934-2:1999 (grab method), the force and elongation were measured using a constant rate of extension machine (INSTRON 5565) with the maintained load and extension speed of 5000 N and 76 mm/min, respectively. SPSS 29 statistical software was then used for statistical analysis at $p < .05$. Simple linear regression analysis was performed to uncover the relationship between load and stretchability for the textile samples with various orientation angles. Stretchability was investigated within the range of elasticity under low load conditions so that no permanent deformation takes place, and the sample can self-reverse once the applied load is removed. Thus, for this experiment, 6 N and 4 N was set as the low load condition for 3D printed textiles with re-entrant and floral auxetic structures, respectively, to simulate the real-life usage.

Results and discussion. As shown in Figure 1, the load-elongation slope decreases in steepness with an increase in orientation angle for both structured samples, indicating that less force is needed to elongate the sample with the rise of orientation angle. The results revealed a statistically significant regression between load and elongation for re-entrant 25 ($F(1,1377) = 3391.99$, $p <.001$), re-entrant 30 ($F(1,1377) = 3933.27$, $p <.001$), and re-entrant 35 ($F(1,1379) = 8414.62$, $p <.001$). Elongation accounted roughly for 71%, 74%, and 86% of the variance in the applied load for entrant 25, re-entrant 30, and re-entrant 35, respectively. Furthermore, according to the regression analysis, elongating re-entrant 25 and re-entrant 30 by 1 mm requires a load of 0.06 N, whereas elongating re-entrant 35 by 1 mm requires a load of 0.04 N. Thus, for 3D printed re-entrant structure textiles, the required load to elongate the sample decreases when the orientation angle of center facing arms increases, resulting in improved stretchability.

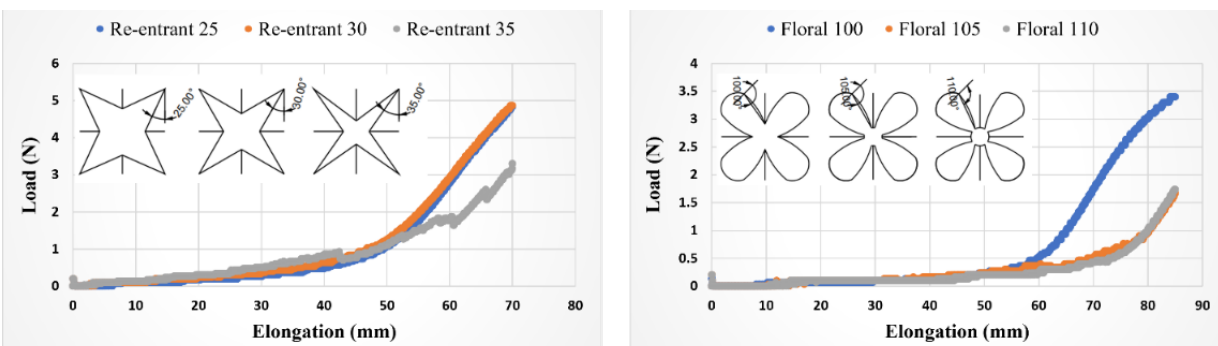

Figure 1. The load-elongation curve of 3D printed auxetic structure textiles with various orientation angles

A statistically significant regression was found between load and elongation for floral 100 ($F(1,1673) = 3168.18$, $p <.001$), floral 105 ($F(1,1673) = 3898.59$, $p <.001$), and floral 110 ($F(1,1673) = 2478.87$, $p <.001$). Additionally, elongation explained 65%, 70%, and 60% of the variance in the applied load for floral 100, floral 105, and floral 110, respectively. The results also indicated that a load of 0.03 N is needed to elongate floral 100 by 1 mm, while 0.01 N is needed to elongate floral 105 and floral 110 by the same amount. Therefore, as the orientation angle of center facing arms increases, the necessary force to elongate 3D printed floral structure textiles decreases, leading to increased stretchability.

© 2024 The author(s). Published under a Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Conclusion. With the emphasis on wearers' comfort, this exploratory study investigated the effect of orientation angle of center facing arms on stretchability of 3D printed re-entrant and floral structure textiles. The results revealed that as the orientation angle increases, stretchability of 3D printed auxetic structure textiles improves, which makes textiles be more flexible and may lead to provide better comfort for wearers. The results showcase the possibility for textile researchers and designers to manipulate stretchability for maximizing wearers' comfort on 3D printed textiles by adjusting their orientation angle of center facing arms in the 3D modeling stage. Although this study provides critical insights for researchers and designers by investigating stretchability of 3D printed auxetic structure textiles with various orientation angles, only two geometries of auxetic structures were employed in this study. Further research needs to be pursued for exploring 3D printed auxetic structure of different geometries.

References

Anderson, I. (2017). Mechanical properties of specimens 3D printed with virgin and recycled polylactic acid. *3D Printing and Additive Manufacturing*, *4*(2), 110-115. https://doi.org/10.1089/3dp.2016.0054

Biswas, M. C., Chakraborty, S., Bhattacharjee, A., & Mohammed, Z. (2021). 4D printing of shape memory materials for textiles: Mechanism, mathematical modeling, and challenges. *Advanced Functional Materials*, *31*(19). https://doi.org/10.1002/adfm.202100257

Kabir, S., Li, Y., Salahuddin, M., & Lee, Y. A. (2023, OnlineFirst). Drapability of 3D-printed auxetic structure textiles for wearable products through the digital image processing technique. *Clothing and Textiles Research Journal*. https://doi.org/10.1177/0887302X231202223

Oladapo, B. I., Bowoto, O. K., Adebiyi, V. A., & Ikumapayi, O. M. (2023). Net zero on 3D printing filament recycling: A sustainable analysis. *Science of the Total Environment*, 165046. https://doi.org/10.1016/j.scitotenv.2023.165046

Penava, Z., Penava, D. Š., & Lozo, M. (2020). Experimental and analytical analyses of the knitted fabric off-axes tensile test. *Textile Research Journal*, *91*(1-2), 62-72. https://doi.org/10.1177/0040517520933701

Shajoo, S., Schmelzeisen, D., & Pastore, C. M. (2021). Auxetic structures from 3D printed hybrid textiles. *Communications in Development and Assembling of Textile Products*, *2*(1), 91-102. https://doi.org/10.25367/cdatp.2021.2.p91-102

Shaw, V. P., & Mukhopadhyay, A. (2021). Behaviour of stretch denim fabric under tensile load. *Fibers and Polymers*, *23*(1), 295-302. https://doi.org/10.1007/s12221-021-0456-5

Spahiu, T., Canaj, E., & Shehi, E. (2020). 3D printing for clothing production. *Journal of Engineered Fibers and Fabrics*, *15*, 1-8. https://doi.org/10.1177/1558925020948216

Voyce, J., Dafniotis, P., & Towlson, S. (2005). Elastic textiles. In R. Shishoo (Ed.), *Textiles in sport* (pp. 204-230). Woodhead Publishing. https://doi.org/10.1533/9781845690885.3.204

Wu, S., Zeng, T., Liu, Z., Ma, G., Xiong, Z., Zuo, L., & Zhou, Z. (2022). 3D printing Technology for smart Clothing: A topic review. *Materials*, *15*(20), 7391. https://doi.org/10.3390/ma15207391

© 2024 The author(s). Published under a Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Xiao, Y., & Kan, C. W. (2022). Review on development and application of 3D-printing technology in textile and fashion design. *Coatings*, *12*(2), 267. https://doi.org/10.3390/coatings12020267

Yang, C., Vora, H. D., & Chang, Y. (2018). Behavior of auxetic structures under compression and impact forces. *Smart Materials and Structures*, *27*(2), 025012. https://doi.org/10.1088/1361-665x/aaa3cf

© 2024 The author(s). Published under a Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.