The effect of 3D-printed auxetic structures on fabric Poisson's ratio

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Introduction

Poisson's ratio (PR) is defined as the negative ratio of the transverse strain to the applied axial strain [1]. With advancements in manufacturing technologies, researchers are now able to alter the PR to fabricate materials with a negative PR [2]. These engineered structures with negative PR are a class of mechanical metamaterials. Researchers have even printed 3D structures that have shown negative PR and have been used for improved impact protection, indentation resistance and other impact protection [3, 4]. Recent research has looked at the importance of the PR of fabrics [5,6] and some researchers have also manufactured auxetic woven fibres using non-auxetic yarns [7] through different knitting and weaving techniques. This research focuses on the effect of embedding printed structures (auxetic and non-auxetic) on fabric and understanding its impact on PR.

Methods

For this study, one type of Fabric – Forest Green Polyester Tulle (Swincraft 2, Birmingham, UK) was used and its PR was analysed (i) without any printed structure in comparison to a non-auxetic (Figure-1-D) and a bowtie auxetic structure[4] printed using (ii) PLA – (Ultimaker, black) and (iii) TPU (NinjaFlex 85A, midnight black). To facilitate measurement before and after testing, four marker dots (5 mm diameter dots) were 3D printed onto each sample (Figure 1 A). Tracking markers and auxetic structures were printed out using Ultimaker S5 (Ultimaker, Netherlands) and the Tulle fabric was incorporated by pausing the print after one complete layer was printed. The fabric was taped to the printer bed to control the stability and the orientation of the fabric for the remaining 15 resulting in a print thickness of 2.5 mm. The fabric was cut into a square measuring 100 × 100 mm using the outer edges of a stencil which was laser cut with the marker locations (Figure 1B). The cut sample was then mounted onto the universal testing machine (Instron, UK) (Figure 1C) and stretched in the vertical axis.

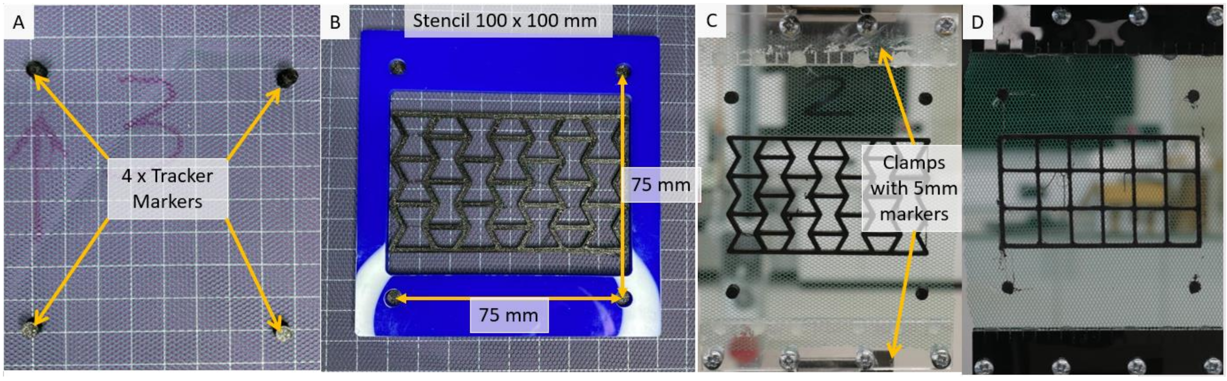

Figure 1: Figure showing (A)the tracking markers printed on a sheet of fabric, (B) shows the stencil used to measure and cut the fabric and (C) sample mounted in the clamp for testing and (D) non-auxetic structure.

Three samples each of the bare fabric, fabric with structures PLA and fabric with TPU bowtie structure were tested at 2 strains, resulting in a total of 24 tests. The distance between the jigs was consistently set at 100mm for the beginning of each test. The samples were pulled to a strain of 10% (10mm) and 20% (20mm) at a rate of 10mm/min for ease of calculations. Photos were taken using a camera (Lumix, Panasonic, Japan) before and after the strain was applied and maximum force was noted. The photo was then imported into Phantom Camera Control Software (Version 3.8, Ametek, USA). The markings on the clamps were used to calibrate the image and the tracker markers were tracked to measure strain in both the axis and to calculate the PR.

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Results

The PR of the fabric alone increased with increase in strain. The testing of the non-auxetic structures has shown no change in PR between 10% and 20% strain (Figure 2A) though it did increase the stiffness greater than the Auxetic (Figure 2B). Addition of Auxetic structures resulted in a decrease in PR between 10% and 20% strain (Figure 2A). Adding the auxetic structures increased the stiffness of the fabric and 3D printed structure combination (Figure 2B).

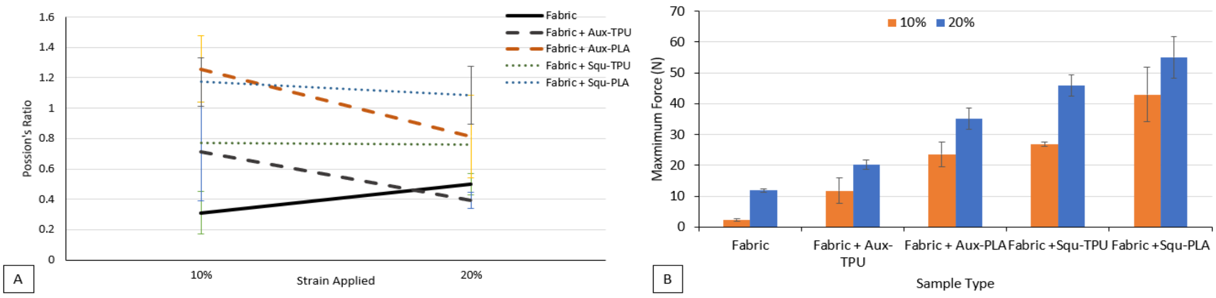

Figure 2: Figure showing (A) Change in Possion's Ratio, (B) Max Force at each strain.

Discussion

Due to working with a fabric that is nonhomogeneous, a PR of greater than 0.5 was observed The PR of the fabric samples increased between the 10% and 20% strain, while the fabric with prints structure showed a reduction in PR. The fabric with PLA structure showed higher change to the PR in comparison to the TPU backed fabric which may be due to the higher stiffness of the PLA. While for this study the bowtie structure was selected, there are many other auxetic structures (and in multiple orientations) that can be investigated to analyse their effect on the fabric. Further studies should look at the overall strain on the surface of the fabric using digital image correlation and the effect of segmenting the prints to allow different properties at different areas of the material. This study shows that it is possible to tailor the stiffness and PR of a fabric and shows the potential of merging additive manufacturing to create fabrics which can be used as personal protective equipment.

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