Fabrication of auxetic foam in a pressure vessel for sports applications

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Auxetic foam, which has a negative Poissons ratio (fattens when stretched), could improve sporting protective equipment and footwear [1,2]. Potential benefits of auxetic behaviour include unique shape change (e.g. domed curvature), potentially improving equipment fit and comfort, and high indentation resistance [1,2]. Sporting protective equipment and footwear often use closed cell foam as padding, with Young's moduli of ~1 MPa [3]. Open cell auxetic foam, made by compressing conventional foam to buckle cell walls (Figure 1a & b), then heating and cooling to fix the imposed structure over time, is typically ~10 times softer than foam used in sports equipment [2]. Methods for making auxetic closed cell foam are less established than those for auxetic open cell foam. Recent work has used steaming process to make auxetic closed cell foam [4,5]. Steam processing uses simple equipment (container and conventional oven), but it may be unsuitable for mass production, as it is time consuming and processing conditions vary with sample shape and size [4].

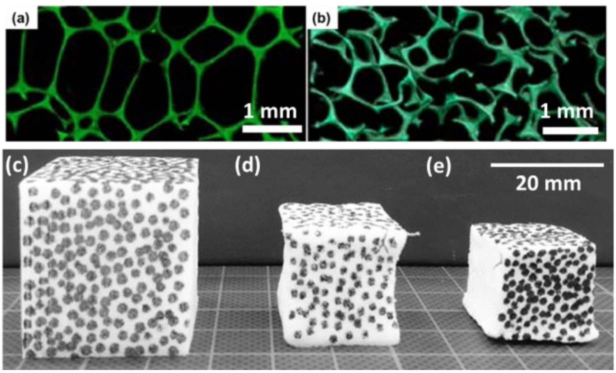

Figure 1: Micro computed tomography of (a) conventional and (b) auxetic open cell foam cellular structures, adapted from open access publication [2]. (c) to (e); Image showing a selection of samples; (c) Unconverted LD45, (d) FVR = 3 & (e) FVR = 5 samples, with speckle pattern applied to facilitate strain mapping.

Building on early, unrepeated work published in 1996 [6], we used a pressure vessel to make auxetic closed cell foam; clarifying methods, investigating whether faster fabrication is possible and whether ideal processing conditions (time,

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temperature & pressure) vary with samples size. Pressure vessels were made by adapting vacuum fittings (Edwards Vacuum – NW50 Full Nipple Stainless Steel and fittings). Thirty closed cell foam samples with various dimensions (10 to 100 mm sides) and densitites (PlastaZote LD24 and LD45, supplied by Advanced Seals and Gaskets, UK), similar to foam used in our steam processing work [4], were processed. Pressures were between 400 and 700 kPa, durations were between 6 and 24 hours, with temperature set to 105°C (the foam softening temperature). Final volume ratios (FVR, original/final volume) were between 2 and 5 (Figure 1c to e), covering the range found to give a negative Poisson's ratio with steam processing [4] – with processing pressure and time both found to increase FVR. For the same processing conditions, similar FVRs were achieved for samples of varying original size (10 × difference, with FVR of 2.5 and 3 for the largest and smallest samples, respectively). As such, the pressure vessel method may be preferable to steam processing when developing manufacturing methods.

Foam samples were quasi-statically tested to 20% compression, with full-field strain measurements using 3D digital image correlation (GOM Correlate, Professional). Young's moduli and Poisson's ratio were calculated from engineering stress vs. axial strain and lateral vs. axial strain data, respectively. Young's moduli were between 0.3 (FVR ~3) and 0.9 MPa (FVR ~4) for processed foams, and 0.4 (LD24) to 0.9 MPa (LD45) for unconverted foam, as expected [4]. Poisson's ratios were between 0.2 (FVR ~2) and −0.2 (FVR ~3) for processed foams, becoming negative for FVRs above 2.5. The Poisson's ratio of unconverted foam was ~0.4, as expected [4]. Future work will focus on impact testing auxetic closed cell foams.

References

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