Fabrication of auxetic closed cell foam in a pressure vessel

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Introduction

Auxetic foam has potential to improve sporting protective equipment, prosthesis and footwear, to name a few [1,2]. Such devices often use closed cell foam as padding, with Young's moduli of ~1 MPa [3]. Open cell auxetic foam is the most researched auxetic foam, but its stiffness is typically about ten times lower than that of the closed cell foam used in sports equipment [2], and other forms of padding. Open cell auxetic foam is made by first compressing conventional foam to buckle cell walls, leaving re-entrant like cells (Figure 1), which can then be fixed over time by heating and cooling.

Fabrication methods for auxetic open cell foam are established, but methods for making auxetic closed cell foam are not. Recent methods have used steam processing to fabricate auxetic closed cell foam [4–6]. The method uses simple equipment (container and conventional oven), but it is unsuitable for mass production, as it is time consuming and processing conditions vary with sample shape and size. A 100 x 100 x 20 mm sample requires a processing time of about eight hours, and a further three days curing for water to leave foam cells [4]. We are building on early, unrepeated work published in 1996 that used a pressure vessel to fabricate closed cell foam [7]. The foam used in the previous work was about ten times stiffer (50 to 200 MPa) than the closed cell foam typically used in sports equipment. We aim to clarify the fabrication procedure, then investigate whether rapid fabrication is possible when using softer foam.

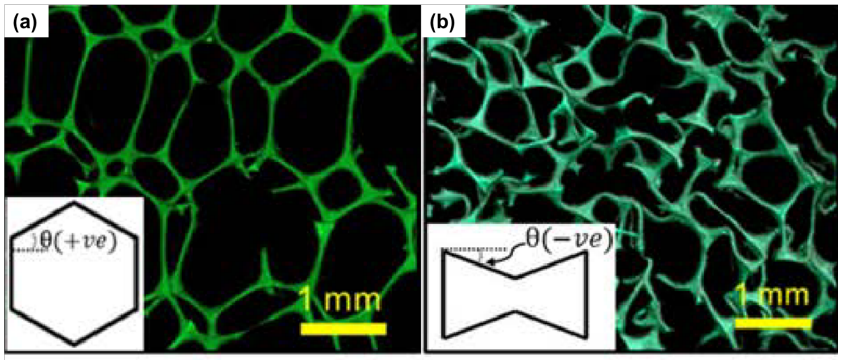

Figure 1: Micro computed tomography, showing (a) conventional and (b) auxetic open cell foam cellular structures. θ shows the angle of oblique cell ribs. Image adapted from open source publication [2], reproduced here with authors permission.

Methods

Experimental work is scheduled in June and July.

Three pressure vessels, made by adapting vacuum fittings (Edwards Vacuum – NW50 Full Nipple Stainless Steel and fittings – certified for use up to 1,000 kPa), will be used to make auxetic foam from the PlastaZote LD-60 foam used in previous steam processing studies [4,5]. Foam cubes (30 mm sides) will be placed inside the pressure vessels, when set to different pressure (e.g. 250, 300 and 350 kPa - maximum allowable operating pressure will be 400 kPa). The vessels will be heated in an oven (Carbolite PF60) for a set time (e.g. 8 hours) at 100 °C, based on previous work [7], then cooled at room temperature before being depressurised. Following measurement of foam dimensions, processing conditions will be tailored so the volume of processed foam samples is between two to four times the original volume – based on values which produced auxetic foam following steam processing [4,5]. Finally, the process will be repeated, increasing pressure, and aiming to reduce processing time.

Vessel temperature and pressure will be monitored during processing, using a thermocouple (RS PRO, Type K, 1100°C) and pressure gauge (RS PRO, 10 bar Bottom Entry Pressure Gauge). Foam which shrinks by two to four times during processing will be quasi-statically tested in compression, in all three orthogonal axes, with full-field strain measurements taken using 3D digital image correlation (GOM Correlate, Professional). Young's modulus will be calculated from engineering stress vs. strain data from the test devices load cell and sample measurements. Poisson's ratio will be calculated from lateral vs. axial strain data.

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