THE MANUFACTURE AND MECHANICAL PROPERTIES OF A NOVEL NEGATIVE POISSON'S RATIO 3-COMPONENT COMPOSITE

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ABSTRACT

Materials with a negative Poisson's ratio known also as auxetic materials [1] exhibit unusual property of getting thicker when stretched and thinner when compressed. The helical auxetic yarn (HAY) is a recently invented auxetic reinforcing structure for composites [2]. A helical auxetic yarn (HAY) consists of two fibres: a low modulus elastomeric core and a high modulus wrap fibre in a double helix structure. When a tensile load is applied the core of the HAY becomes wider as the wrap straightens out, resulting in a lateral expansion of the core, and therefore a large negative Poisson' ratio behaviour. The auxetic behaviour of the HAY can be tailored by altering fibre properties, the initial geometry and also the applied strain to comply with specific applications, such as composites [3, 4], blast mitigation, and filtration [5]. This paper introduces a further development to the current HAY by addition of a third component (a sheath). The presence of the sheath is expected to overcome problems such as slippage of the wrap and inconsistency in the initial wrap angle previously encountered during the manufacture of the HAY. The auxetic performance of conventional and novel systems is investigated and Poisson's ratio data are presented.

1 INTRODUCTION

Materials with a negative Poisson's ratio are called auxetic materials [1], which expand laterally when stretched longitudinally. Since 1987 a range of auxetic materials have been discovered and fabricated [6-21]. The helical auxetic yarn (HAY) is one of the most exciting auxetic structures [2] and it comprises an elastomeric core and a stiff helix wrap, see Fig. 1.

The HAY has been well investigated in terms of its fabrication and mechanical properties [3, 4, 22-25]. However, the existing HAY has problems in poor conformance between the core and the wrap fibres during its manufacturing process. This paper proposes a novel 3-component auxetic structure which could provide a solution for above problems as shown in Fig. 2. The aim of this study is to find out whether a 3-component auxetic structure will overcome poor conformance problems in manufacturing HAY.

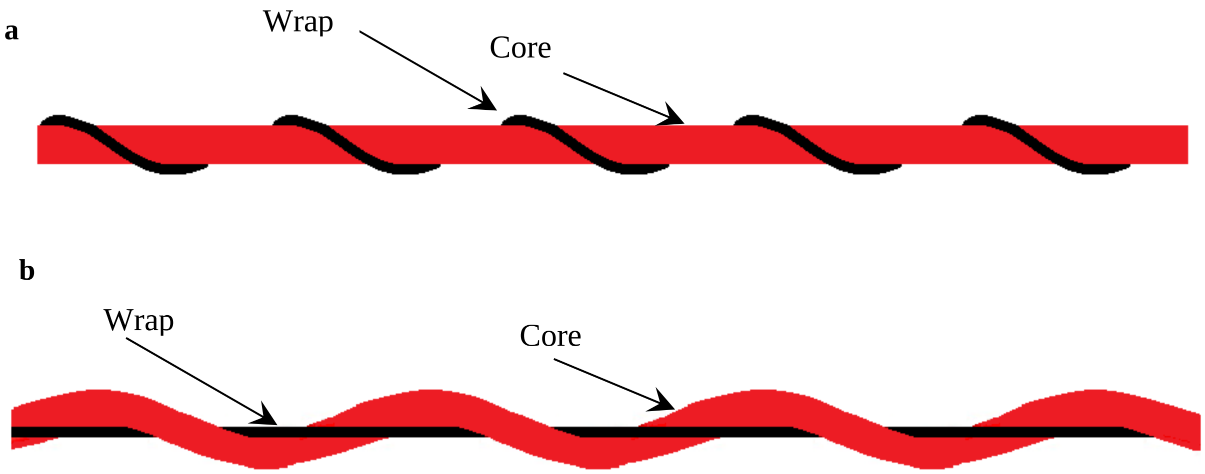


Figure 1: Illustration of the HAY [25]: (a) HAY at zero strain and (b) HAY at maximum strain.

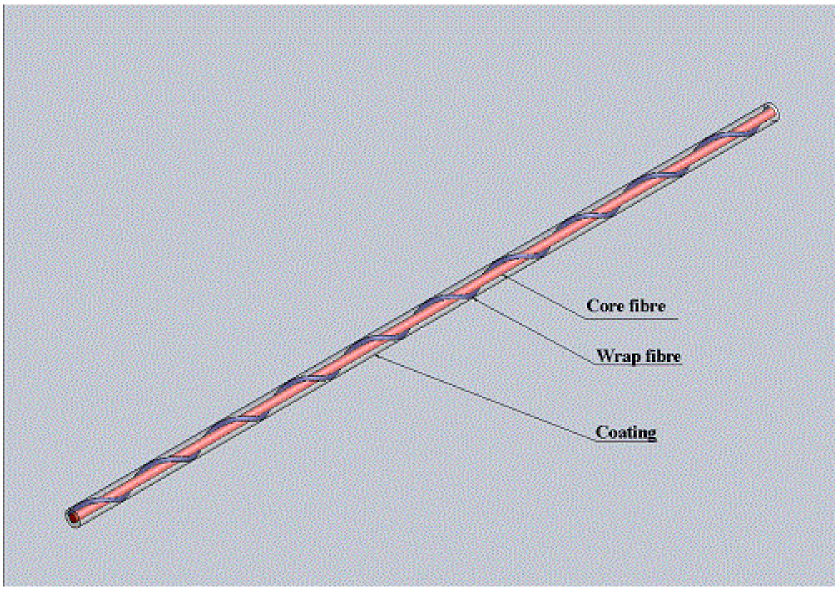


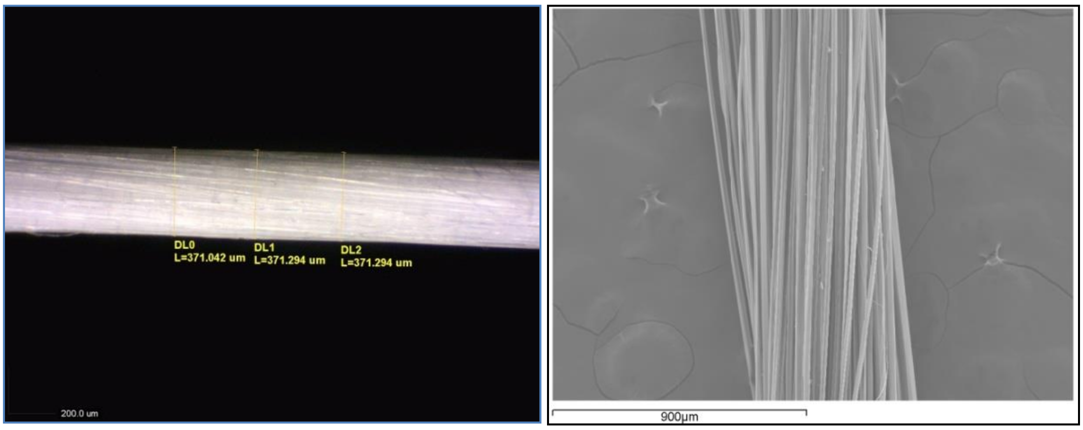
Figure 2: 3-component auxetic structure.

2 METHODS

The core fibre was made via mixing silicone rubber gel (VTV750) and catalyst (CAT 740/750). A twisted ultra high molecular weight polyethylene (UHMWPE) multifilament fibre was selected as the wrap fibre, see Fig. 3. The HAY was manufactured manually by pre-determining cyclic pitch of the wrap fibre (λ). The initial wrap of the HAY was maintained at 40^{o} in this work. Finally, the 3-component auxetic composite was manufactured by enclosing the HAY with a sheath of silicone rubber gel using a bespoke mould. Typical properties of fabricated fibres, HAYs and 3-component auxetic composites are shown in Table 1.

Type	Silicone core diameter (mm) (+/- 0.1mm)	UHMWPE Wrap diameter (mm) (+/- 0.03mm)	Initial wrap angle (°)	Coating thickness (mm)	Young's modulus (MPa)
Core fibre	14	-	-	-	2.1 ± 0.3
UHMWPE wrap	-	0.37	-	-	23,000 ± 3,000
Helical auxetic yarn	14	0.37	39.2± 1.0	-	2.2 ± 0.3
3-component auxetic composite	14	0.37	41.6±1.8	4	1.8 ± 0.2

Table 1: Fabricated helical auxetic yarns and 3-component auxetic composites.



(a) **(b)**

Figure 3: UHMWPE multifilament wrap fibre: (a) optical image and (b) SEM image.

The mechanical measurements of all the samples in Table 1 were carried out according to ASTM D3822-07 – tensile properties of single textile fibres [26]. The sample gauge length was set as 80 mm and an additional gauge length for optical longitudinal strain measurements was marked onto the sample. 3 random samples were tested for each sample type. A 4.9 MP digital camera (Edmund Optics EO-5012C USB) was utilised to capture images at regular strain intervals. Acquired images were employed to analyse longitudinal and transverse sample strain. A typical 3-component auxetic composite under tensile measurement is shown in Fig. 4. Image analysis and strain measurements for these samples were carried out based on Sloan et al.'s previous work [23].

Engineering Poisson's ratio (ν_{xy}) was calculated using obtained engineering strains ε_y and ε_x.

$$\nu_{xy} = -\frac{\varepsilon_y}{\varepsilon_x} \tag{1}$$

Instantaneous true Poisson's ratio was calculated by taking local tangents from true strain-true stain graphs.

$$\nu_{xy}^{int} = -\frac{\varepsilon_y^{int}}{\varepsilon_x^{int}} \tag{2}$$

where ν_{xy}^{int} is instantaneous true Poisson's ratio, and ε_x^{int} and ε_y^{int} are instantaneous true longitudinal strain and transverse strain, respectively.

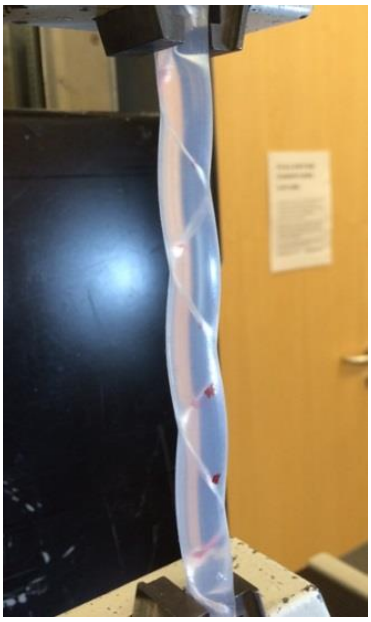


Figure 4: Picture of a typical 3-component auxetic composite in the tensile test.

3 RESULTS AND DISCUSSION

In this paper, four different samples were prepared and tested: silicone rubber core fibre, UHMWPE wrap fibre, helical auxetic yarn and 3-component auxetic composite. Table 1 shows typical properties of all the samples. The Young's modulus was calculated using the small strain region (0.05-0.25% [27]).

Pure 14 mm silicone rubber core fibre was employed to fabricate the HAY and 3-component auxetic composite. Fig. 5 shows the Poisson's ratio analysis for 14 mm silicone rubber core fibre. The original dimension data were smoothed using a polynomial fitting method in order to remove unwanted noise so that the true Poisson's ratio can be computed accurately. Overall, the true Poisson's ratio of 14 mm core is higher than that of engineering one, as shown in Fig. 5c. Note that in both cases the Poisson's ratio were 'well-behaved' as a typical elastomeric material.

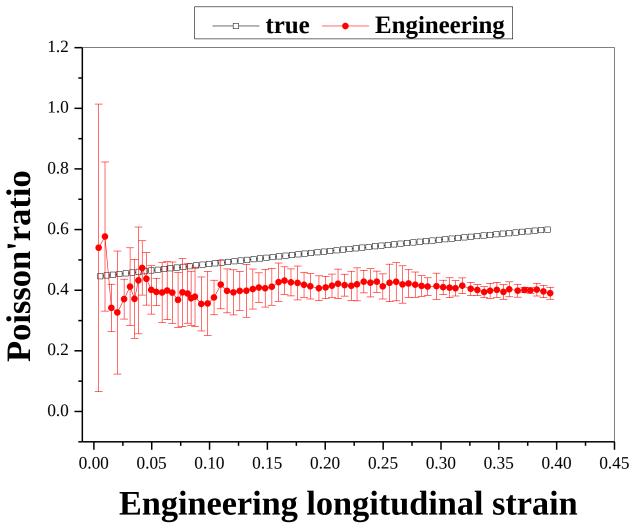


Figure 5: Poisson's ratio analysis for 14 mm silicone core: ν_{xy}^{int} and ν_{xy} vs ε_x.

The core to wrap diameter ratio is a significant geometric parameter to tailor the auxetic performance of a HAY. A HAY with 14 mm silicone rubber core was fabricated. The Poisson's ratio analysis for the yarn was carried out in the same manner as 14 mm core fibre. Fig. 6 compares the engineering and true Poisson's ratio of the yarn as well as the core fibre. It indicates that calculated true Poisson's ratio of the core fibre maintains around 0.5, and the engineering and true Poisson's ratio of the yarn become negative at very low strains and at almost same time, then the true Poisson's ratio becomes positive again while the engineering one remains negative after the strain of 0.225. It is worthy to note that the true Poisson's ratio of the HAY approaches that of the core fibre at the end of the tensile test. Therefore, in practice in order to keep Poisson's ratio remains at a negative value the strain definition is essential.

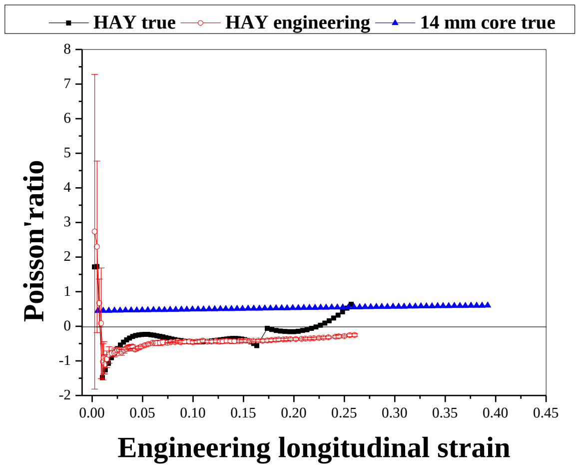


Figure 6: Poisson's ratio analysis for helical auxetic yarn with 14 mm core: ν_{xy}^{int} and ν_{xy} vs ε_x.

The 3-component auxetic composite was fabricated with a 14 mm silicone rubber core and UHMWPE wrap coated with a 4 mm coating. Fig. 7 shows that the engineering Poisson's ratio is decreasing as a function of strain and approaches zero and becomes negative at the strain of around 0.25. Nevertheless, the true Poisson's ratio is also decreasing with applied strain but its crosses zero point much earlier than the engineering Poisson's ratio at the strain of around 0.1, then it becomes increasingly negative until reaches the maximum value. A sharp increase to positive at the end of true Poisson's ratio curve is due to a sharp decrease of sample width. Fig. 7 demonstrates that a 3-component auxetic composite will still have an auxetic behaviour after coating process in terms of engineering and true Poisson's ratio.

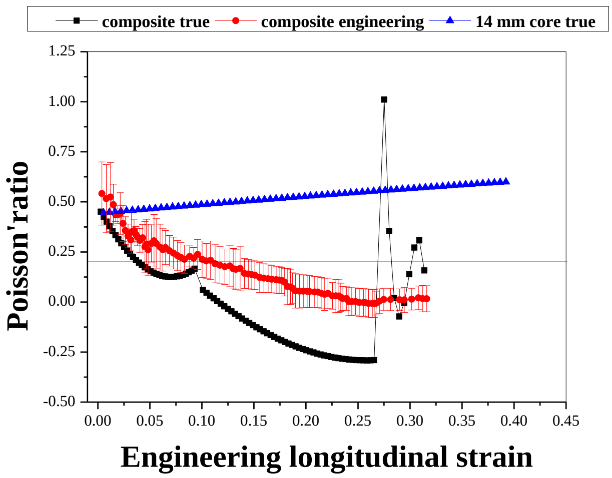


Figure 7: Poisson's ratio analysis for 3-component auxetic composite with 14 mm core and 4 mm coating: ν_{xy}^{int} and ν_{xy} vs ε_x.

4 CONCLUSIONS

This paper proposes a novel 3-component auxetic structure and attempts to offer solutions for previous problems in manufacturing HAY. The results demonstrated that it was possible to fabricate a 3-component structure with a negative Poisson's ratio. The auxetic behaviour is not diminished by an appropriate layer of coating. However, the magnitude of the auxetic effect is reduced due to a coating process. The coating thickness can be utilised as a new design parameter to tailor the Poisson's ratio of a 3-component auxetic composite for different potential applications.

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