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Development, characterization and analysis of auxetic structures from braided composites and study the influence of material and structural parameters

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ABSTRACT

Auxetic materials are gaining special interest in technical sectors due to their attractive mechanical behaviour. This paper reports a systematic investigation on missing rib design based auxetic structures produced from braided composites for civil engineering applications. The influence of various structural and material parameters on auxetic and mechanical properties was thoroughly investigated. The basic structures were also modified with straight longitudinal rods to enhance their strengthening potential in structural elements. Additionally, a new analytical model was proposed to predict Poisson's ratio through a semi empirical approach. Auxetic and tensile behaviours were also predicted using finite element analysis. The auxetic and tensile behaviours were observed to be more strongly dependent on their structural parameters than the material parameters. The developed analytical models could well predict the auxetic behaviour of these structures except at very low or high strains. Good agreement was also observed between the experimental results and numerical analysis.

1. Introduction

Poisson's ratio is defined as the lateral strain to the longitudinal strain for a materials undergoing tension in the longitudinal direction. In common, all materials possess positive Poisson's ratio, i.e. the materials shrink laterally under tensile loading, and expand transversely when compressed. However, in auxetic materials the phenomena is just reverse, i.e. when material stretched it expands transversely and contracts during compression that is, they exhibit negative Poisson's ratio (NPR) [1–9]. Negative Poisson's ratios are theoretically accepted. For an isotropic material, the range of Poisson's ratio is from -1.0 to 0.5, based on thermodynamic consideration of strain energy in the theory of elasticity. However, for anisotropic materials, these range is higher and limits do not apply [2,6,10].

Auxetic materials gains specific interest due to their unusual behaviour which results improved mechanical properties, such as improved fracture toughness, higher indentation resistance, high energy absorption, sound absorption properties, improved shear modulus, hardness, synclastic curvature (dome shape on out-of-plane flexure) in sheets and panels, high volume change, high impact resistance, etc. [2,6–9,11–13].

Diverse range of auxetic materials includes, naturally occurred pyrolytic graphite, cancellous bone, rock with micro-cracks, auxetic three dimensional foams, auxetic bio-materials, auxetic two-dimensional honeycomb, auxetic composites (fibre reinforced plastics or FRPs) auxetic microporous polymers, etc. [2,6,9–11,14]. Auxetic textile materials are widely used as filter, sports clothing, biomedical application, defense industries, etc. Also, auxetic composites can find potential applications in aerospace and automotive industry as well as in materials for protection, where non-auxetic composites with high specific strength and stiffness are currently used [2,6,8,10–12,15].

Besides composites, the auxetic property can also be attained with definite structural designs. In the last few decades, divergent geometric structures and models exhibiting auxetic behaviour have been proposed, studied and tested for their mechanical properties. The main auxetic structures reported are two dimensional (2D) and three dimensional (3D) re-entrant structures, rotating

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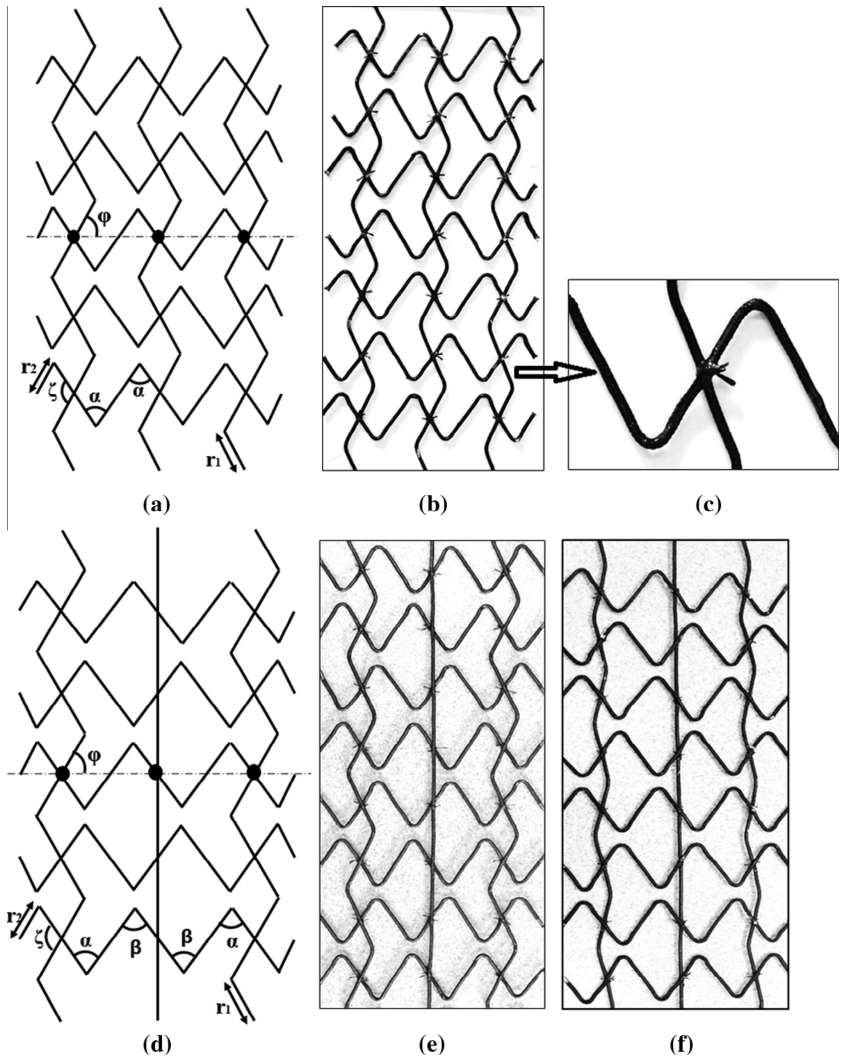

Fig. 1. Auxetic structural design used in the present study showing the structural angles (r_1 – longitudinal rod rib length and r_2 – transversional rod rib length). (a) Schematic of structure-1, (b) real structure-1, (c) portion of structure in close-up, (d) schematic of structure-2 and (e and f) structure-2 and structure-3.

rigid/semi-rigid units, chiral and cross chiral structures, hard molecules, liquid crystalline polymers and microporous polymers [6,7,11,14,16–20,21].

Fibre reinforced polymer composites have been applied widely in civil structural applications due to their enhanced properties as compared to conventional materials (concrete and steel) or ceramic based composites. These properties include high tenacity, low density, higher stiffness and strength, and easy handling. Composites are introduced into structural elements to improve their flexural resistance, shear strength, confinement, bending property, etc. [22–27]. Recently developed braided composite rods (BCRs) are a special class of FRPs, which have been used in structural applications due to their several advantages over the other types of FRPs such as simple and economical manufacturing process, tailorable mechanical properties and good bonding behaviour with cementitious matrices [28–33]. Currently, research is being carried out to employ composite materials in structural elements to improve their resistance against earthquake, blast or impact loads caused by explosions [34–37]. Capacity to absorb energy is one of the principal requirements for these applications and, in this sense, auxetic composites and structures may prove to be excellent materials.

In our previous research study, auxetic structures were developed from braided composite rods based on missing rib or lozenge grid or cross-chiral (Fig. 1a) design and their auxetic and tensile behaviours were studied, mainly focusing on the influence of structural angle [2]. Similar to other studies [17,18], this initial study also showed that the structures based on the cross-chiral configuration exhibited negative Poisson's ratio. However, a recently performed analytical study revealed that the Poisson's ratio in the cross-chiral structures should be zero [20]. The equivalent negative Poisson's ratio which was observed in the experimental studies was the result of uniaxial shear coupling existing in these structures [20]. In contrast to our previous work [2], which only considered the influence of structural angle on auxetic and tensile behaviours, the influence of all important structural and material parameters has been considered in the present work. Moreover, the previous work considered the existing analytical model (based on the hinging mechanism, according to Refs. [17,18]) to predict the auxetic behaviour of developed structures leading to no correlation between the experimental and analytical results. To overcome this, in the present work a new analytical model (based on the hinging mechanism, but with additional parameters) has been proposed both for the basic and modified structures. Numerical modelling based on finite element (FE) method has also been performed to predict auxetic and tensile behaviours. Also, in the present case, the rib length of the structures has been decreased to increase their closeness and consequently, their strengthening capability for civil engineering applications.