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Design of a cylindrical tube with negative Poisson's ratio via finite element analysis

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ABSTRACT

Background: Materials with specific structural shape can exhibit negative Poisson's ratio and can be widely applied to structural applications such as impact absorbents and fasteners due to their superior resilience and resistance to impact [1]. To induce its characteristic, previous studies postulated many structural shapes such as non-convex shape with re-entrant corners and re-entrant honeycomb [1-2]. Previously author had analyzed the 2D materials with the rotational particle structures and investigated the Poisson's ratio with the ratio (E_e/E) of the elastic modulus of these structures [3]. In this study, the rotational particle structure was applied to a cylindrical tube with negative Poisson's ratio and their material properties were studied *via* finite element analysis.

Method: The auto-meshing preprocessor was coded using MATLAB in order to construct numerical models from design parameters and perform finite element analysis (FEA) effectively. Three main parameters were the ratio of fibril's length to particle's diameter (L/D), the ratio of fibril's width to its length (W/L) and the angle of fibril (θ) about horizontal axis as of our previous study and Particle's diameter was fixed with the value of 6.0 mm (Fig. 1). Finite element model had 3D brick quadratic element and composed of 343 particles and 6-linked fibrils per each particle. In this study, we performed two types of mechanical analyses. One was the uniaxial tensile analysis by 0.1% strain and the other was the expansion analysis by the inner pressure of 1 MPa. After performing finite element analysis, Poisson's ratio and the ratio (E_e/E) of the elastic modulus according to the various design parameters were studied. Mechanical properties of particles and fibrils were the value of ultra high molecular weight polyethylene (UHMWPE): the elastic modulus, 1GPa and Poisson's ratio, 0.35.

We also made 3D tubes with negative Poisson's ratio by rapid prototyping to validate the effect of negative Poisson's ratio.

Result and Discussion: The result for the tensile analysis indicated that it was possible to design a cylindrical tube with negative Poisson's ratio by composing the rotational particle structure as our previous study. In other words, the tube was expanded in the radial direction for the axial tensile strain. Poisson's ratio was decreased as the increase of fibril's angle, and the variation of Poisson's ratio was increased as the ratio of fibril's width to its length was decreased. The ratio of elastic modulus of these structures decreased with the negative Poisson's ratio. For the expansion analysis, the model with the fibril's angle of 40 degree had about three times strain as that of 0 degree for the same inner pressure. The result showed that the tube with negative Poisson's ratio offered the superior expandability.

This study showed that the Poisson's ratio of the rotational particle tube was able to be controlled by design parameters. Particularly the fibril's angle was the major parameter which could significantly affect Poisson's ratio of the tube. This structure also has the potential for use as the airway or esophageal stent.

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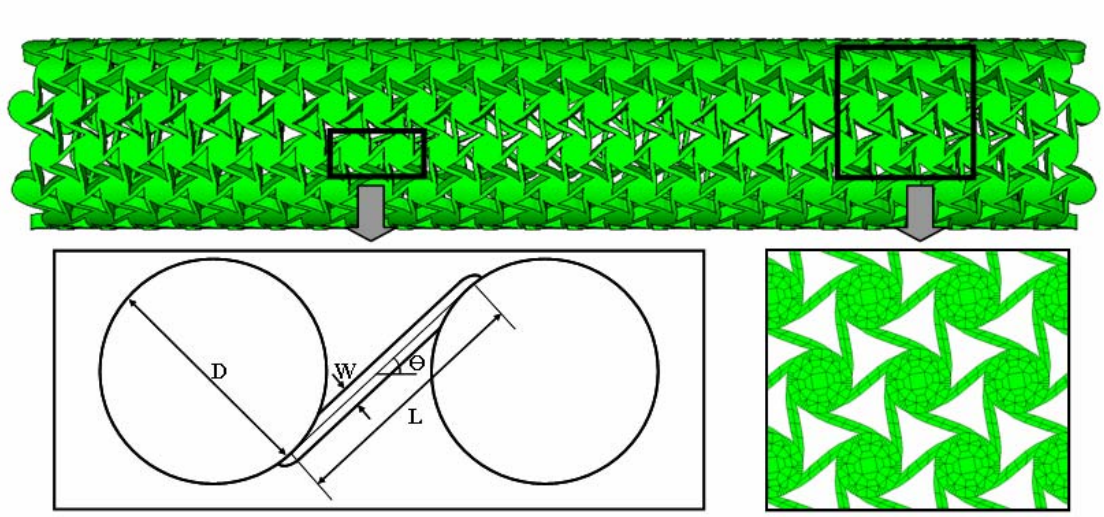

Fig. 1. Finite element model of tube with a negative Poisson's ratio (top), its design parameters (bottom-left) and its meshing pattern (bottom-right)