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Textile Materials and Structures with Negative Poisson's Ratio – An Overview

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Abstract

Material with negative Poisson's ratio is a kind of new structural material with special physical properties and geometric structure, which undergoes a transverse expansion when stretched in longitudinal direction and a transverse contraction when compressed. Compared with common textile materials, auxetic textile materials are significantly different in terms of thier structures and properties. Thereof, reviews on auxetic materials of foam, polymer and textile materials were investigated, and the mechanism of the dilation property was analyzed and obtained in this paper. It is found that these auxetic materials are dependent on the microstructures with reentrant structures or rotating structures. The analysis of the structure of materials with negative Poisson's ratio can contribute to the new textile material technology and new functional textile products, such as magnetic-shielding fabrics and water-repellent/wind-proof fabrics. It is also helpful in infrastructure, aerospace engineering, biomedical engineering and environmental engineering.

Keywords: Negative Poisson's Ratio; Fabric; Fibre; Polymer; Foam

1 Introduction

Poisson's ratio is defined as the negative transverse strain divided by the axial strain in the direction of stretching force. Common materials undergo a transverse contraction when stretched in one direction and a transverse expansion when compressed, which are called positive Poisson's ratio of materials, such as Poisson's ratio of rubber is 0.5. In contrast, some materials undergo a transverse expansion when stretched in one direction and a transverse contraction when compressed, which are called negative Poisson ratio material, also called the auxetic materials, such as Poisson's ratio of yellow single crystal iron ore is −0.14. Poisson's ratio is generally in the range of −1 to 0.5 for isotropic continuous materials and Poisson's ratio of common foam varies from 0.1 to 0.4 [1].

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Different Poisson's ratios affect materials' performance significantly. For tensile fracture analysis, transverse cross section of positive Poisson's ratio material decreases gradually when stretched, and the fracture always occurs at middle section for transverse contraction; while transverse cross section of negative Poisson's ratio material increases gradually when stretched. Although the fracture opposition often generates at middle section, it is for transverse expansion. Thereof, the tension fracture analysis becomes much more complex. Meanwhile, for compression, positive Poisson's ratio materials are easily crushed when their section become flat and density descends; while materials section with negative Poisson's ratio becomes tougher for being assembled to high density when compressed, such as human joints skin, cow nipple skin and foam. Compared with common materials, auxetic materials with negative Poisson's ratio have higher shear modulus, higher storage modulus as well as have excellent bulk elastic modulus and crush resistance property [1]. Materials with negative Poisson's ratios have been theoretically verified in 1940s, and developed in recent 30 years as foam materials. It is a kind of new structural material and research in this textile field is also happening for nearly 20 years. Textile products have made great contributions into aerospace, while new functions and application of textile materials are required more strictly, especially for magnetic-shielding fabric. Thereof, if the above kind of fabric is woven from negative Poisson's steel yarns, the shielding effect is greatly improved for space between fibres and yarns being expanded in tensile application. So, it is necessary to have a good review on negative Poisson's ratio of materials, and to provide new concepts related to fabric products.

2 Auxetic Foam and Polymer

2.1 Auxetic Foam

Lakes firstly reported polyester- polyurethane foam with negative Poisson's ratio made in 1987 [2]. It describes that the conventional foam is compressed in three orthogonal directions, and can be changed from positive Poisson's ratio to negative Poisson's ratio by being heated in a mold with a temperature slightly above the softening temperature of the foam material. The microstructure of the foam materials showed that there exists difference between positive and negative Poisson's ratio, where the former structure of foam is an open structure, while the latter structure of foam is compressed into reentrant structure with negative Poisson's ratio, as seen in Fig. 1. The research results lay the foundation for the development of negative Poisson's ratio polymer. Furthermore, Brandel and Lakes also made three-dimensional reentrant microstructure of polyethylene foam by regulating the thermo-mechanical process of common polyethylene foam [3].

Park also obtained negative Poisson's ratio copper foam with three-dimensional reentrant structure using multistage compression method (orthogonal directions) [4]. Robert transformed the open cell structure into negative Poisson's ratio polyisocyanurate foam with three-dimensional reentrant microstructure by controlling compression process [5]. The effects of reentrant structure sizes of these foams were not concerned with, which were the shackles of producing applicable negative Poisson's foam. Evans analyzed effects on the negative Poisson's ratio structure and size of the heating temperature, time, and volume compression ratio and process parameters. It was found that small-size reentrant structure foam could be fabricated by short heating time and low compression load, and large-size reentrant structure foam could be prepared by long heating time