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Short Communication

Energy absorption property of warp-knitted spacer fabrics with negative Possion's ratio under low velocity impact

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ABSTRACT

Auxetic warp-knitted spacer fabric is known for its excellent mechanical properties, shear-resistance, cushioning property, energy absorbing abilities, therefore draws more and more attention to this kind of fabrics. In order to study the impact resistance and energy absorption ability of auxetic warp-knitted spacer fabrics under low-velocity impact, falling weight impact tests are adopted in this paper and influence relations of energy absorption and impact resistance to auxetic performance and initial impact energy are analyzed. Results show that the larger absolute value of negative Poisson's ratio is, the better energy absorption ability and impact resistance could be obtained, and the initial impact energy has little influence on the overall energy absorption of fabrics under low-velocity impact.

1. Introduction

Recently, materials with negative Poisson's ratio fabricated with knitting techniques are gaining more and more attention for exhibiting many excellent properties such as mechanical properties, indentation resistance, shear resistance, breaking tenacity, surface fitting ability and energy absorption property. Fabric materials with negative Poisson's ratio are widely applied in manufacture of protective equipment, automotive industry, aerospace field and national defense industry as a novel kind of structural material. Warp-knitted spacer fabrics are a kind of three-dimensional textile composed of two separate fabrics and spacer yarns connecting and supporting these two pieces which is usually fabricated on double-bed raschel warp knitting machine. With its unique internal space, warp-knitted spacer fabrics are endowed with good compression elasticity, air and moisture permeability, sound absorption, acoustical insulation, structural integrity and formability, thus widely applied in shaped shoe materials, garment fabrics, building reinforcement and packing materials. Auxetic warp-knitted spacer fabric, namely warp-knitted spacer fabric with negative Poisson's ratio, is a combination of auxetic structure and warp-knitted spacer textile which makes it a cutting-edge material, and only after its distinctive properties are known can this kind of new material be effectively put into application.

Choi et al. [1] prepared negative Poisson's ratio copper foam by transforming into a re-entrant shape through sequential permanent compression, and found that Poisson's ratio as small as -0.8 could be achieved with strain dependence and better auxetic performance after annealing. Lakes [2] discussed about materials with negative Poisson's ratio including cellular solids, composites, crystalline and amorphous materials, and how they can be created with specified properties. Ma et al. [3] summarized different kinds of geometrical models of auxetic materials such as re-entrant model, rotating model and chiral model, and also discussed about how knitted textiles are constructed based on these structural models. Ma et al. [4] also produced two-dimensional warp-knitted textiles with negative Poisson's ratio based on rotational hexagonal structure and discussed about the relationship between auxetic performance and structural parameters. Wang et al. [5] reported a novel kind of 3 D auxetic warp-knitted spacer fabric with a configuration formed with parallelograms. Wang et al. [6] also studied deformation behaviors of 3D spacer fabrics reported before and established geometrical models and semi-empirical equations which fit well with experimental results. Wang et al. [7] also reported the tensile deformation behavior of an auxetic warp-knitted spacer fabric structure using finite element method. These researches on auxetic materials and relevant geometrical models helps a lot in the structural design of auxetic warp-knitted spacer fabrics adopted in this paper.

Guo et al. [8] investigated the impact and compression-after-impact properties of warp-knitted spacer fabrics through low-velocity impact tests, damage deformation characterizations and compression tests after impacts. Liu et al. [9] studied the impact compression behavior of a series of warp-knitted spacer fabrics with different structural parameters developed for human body protections using drop-weight

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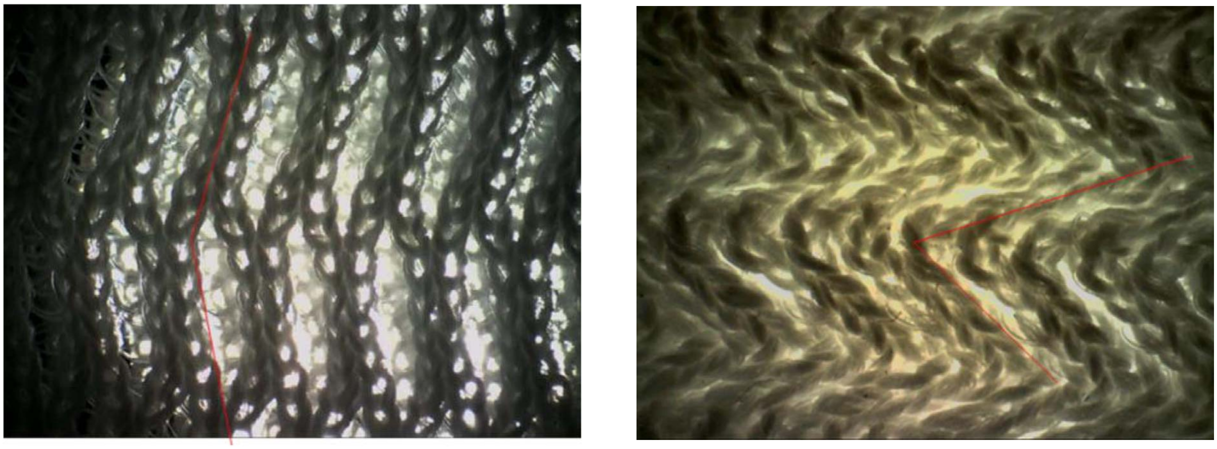

(a) Before heat setting (b) After heat setting

Fig. 1. Comparison top view of fabric structures.

Fig. 2. Comparison lateral view of fabric structures.

Table 1
Average values of Poisson's ratio.

Sample number	1#	2#	3#	4#	5#
Poisson's ratio	−0.375	−0.437	−0.513	−0.614	−0.625

impact tester. Liu et al. [10] also studied the impact compression behavior of cushioning warp-knitted fabrics through compression stress-strain curves and energy efficiency diagrams. Researches on performances of warp-knitted spacer fabrics under low-velocity impact helps with the experimental tests and analysis of energy absorption and impact resistance in this paper.

Considering that there are few researches on the impact resistance and energy absorption of auxetic warp-knitted spacer fabrics under low-velocity impact, five spacer fabric samples with different Poisson's ratios are used for falling weight impact tests to find out how auxetic performance of fabrics and initial impact energy affect its impact resistance and energy absorption ability.

2. Experiments

2.1. Sample preparation

The preparation process of auxetic warp-knitted spacer fabrics is as followed: Step 1, choose a suitable auxetic structure as the model of fabric construction, enabling it easily fabricated using warp knitting techniques; Step 2, select yarn materials enhancing the rigidity of fabric structures to better achieve the deformation of auxetic structures; Step 3, design the fabric structures to coincide with the chosen auxetic model; Step 4, set the knitting parameters carefully to find out their effects on the fabric structure; Step 5, design the heat setting process and its parameters to ensure the auxeticity of fabric samples. Following the aforementioned steps, five kinds of warp-knitted spacer fabric samples are prepared with the first four having different chain notations of GB4 and the last having a different letting-off value from the first sample. The auxetic principle of these fabric samples is that adding additional miss-lapping pillar chain to the typical hexagonal warp-knitted spacer mesh makes the original hexagon mesh uneven so that the hexagons in fabric shrink and deflect regularly under natural conditions and expand to a honeycomb shape when stretched thus exhibiting an auxetic performance. The heat setting process is needed to bring out the deflection effects of fabrics under natural conditions and stabilize the deflected hexagonal structure. Comparison top views of fabric structures before and after heat setting are shown in Fig. 1 and comparison lateral view is shown in Fig. 2. It can be seen from comparison pictures that fabrics get much more compact after hear setting both warp-wise and weft-wise in the fabric plane leading to a much smaller included angle between two ribs marked in red in Fig. 1, and the lateral view of fabrics turns from a smooth linear pattern to a concavo-convex shape marked in red in Fig. 2.

2.2. Poisson's ratio tests

Values of Poisson's ratio are obtained based on it definition, namely the negative ratio of the value of strain perpendicular to the stretch direction to the value of strain along the stretch direction. Samples used for Poisson's ratio tests are cut into the same width of 40 mm and fixed as 50 mm longitudinally with clamps under natural state. Move the downside clamp down 1 mm each time which equals 2% of its original length and at the same time measure its middle horizontal length of the sample. Value of strain is calculated by dividing elongation value by