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A Method to Evaluate the Auxetic Behavior of Warp Knit Fabric

N Gokarneshan[1], Sona M Anton[2], S Umamageshwari[3], Usha Kumar Ratna[4] and P G Anandhakrishnan[5]

[1]*Department of Textile Chemistry, SSM College of Engineering, India*

[2]*Department of Fashion Design and Arts, Hindustan Institute of Technology and Science, India*

[3]*Department of Fashion Designing, CSH, SRM Institute of Science and Technology, India*

[4]*Department of Textiles and Clothing, Avinashi lingam Institute for Home Science and higher education for women, India*

[5]*Department of Fashion Design, Saveetha college of architecture and design, India*

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***Corresponding author:** N Gokarneshan, Department of Textile Chemistry, SSM College of Engineering, India Email: advaitcbe@rediffmail.com

Abstract

A novel class of auxetic warp knitted fabrics has been developed and their auxetic behaviors were studied under a single tensile test. However, during daily use, the fabrics are usually subjected to repeating tension rather than single tension. Therefore, the durability of the fabrics' auxetic performance is of great importance. So far, the auxetic behavior of fabrics under repeating tension has not systematically been investigated. In this paper, we report a study on the auxetic behavior of warp knitted fabrics under repeating tension. All the fabric samples were subjected to a repeating tensile test within a tensile strain of 25% until 100 tensile cycles. The results show that the fabrics can keep their auxetic effect in both course and wale testing directions after 100 tensile cycles, and the auxetic effect in the wale direction is retained longer under higher tensile strains than that under lower tensile strains with the increase of tensile cycles. The results also indicate that auxetic stability in the course direction is much better than that in the wale direction. We hope that this study can offer useful information to improve the auxetic stability of auxetic fabrics for practical use.

Keywords: Auxetic Fabric; Knitted Fabric; Negative Poisson's Ratio; Repeating Tensile Test

Introduction

The Poisson's ratio of materials can be negative, and materials with a negative Poisson's ratio are known as auxetic materials [1,2]. Unlike their conventional counterparts, auxetic materials laterally expand when stretched and laterally contract when compressed [3,4]. As the auxetic behavior of materials is structure-dependent but scale-independent, auxetic materials from the nanoscale and microscale to the macroscale have been extensively studied by researchers in various fields [5-13]. In the field of textiles, great interest has been shown in auxetic fabrics and, consequently, many auxetic fabrics have been realized using knitting, weaving, and non-woven technologies [14-24]. Due to the auxetic behavior of fabrics, a dome shape can be easily formed, which makes auxetic fabrics quite suitable to fit human body curves to enhance comfort. Potential applications of auxetic fabrics include sportswear, smart bandages, blast curtains,16 and smart filters [25]. Compared with weaving, knitting technology is more suitable for developing novel auxetic structures due to its flexibility in fabric design and production. Liu et al. [8] studied auxetic weft knitted fabrics based on foldable structures, which are formed by the zigzag distribution of reverse loops and face loops. When stretched, the foldable fabric structures unfolded, causing an increase in the lateral direction, thus showing auxetic behavior. Hu et al. also proposed auxetic weft knitted fabrics with a foldable structure comprised of alternatively distributed rectangle zones of reverse loops and face loops [14]. In the same research, they also developed another two auxetic weft knitted fabrics based on re-entrant hexagons and rotating rectangles, respectively. All the fabrics they produced were proven to be auxetic under certain extension.

Regarding warp knitting, Ugbolue et al. developed auxetic warp knitted fabrics by introducing elastic yarns into a conventional hexagonal net to form reentrant hexagons [26]. According to them, the structures could exhibit an auxetic effect under stretch. Based on double arrowhead geometry, Alderson et al. produced various auxetic warp knitted fabrics and studied the influence of the knit pattern on the auxetic behaviour [15]. Their study showed that an auxetic effect could be achieved along directions at 45^o to the warp direction. Ma et al. and Chang and Ma fabricated another type of auxetic warp knitted fabric based on a rotational hexagonal structure using single needle bed and double needle bed warp knitting machines, respectively [19,27]. Different from the above methods, Wang and Hu16 adopted an in-plane compression and heat setting process to fabricate auxetic warp knitted spacer fabrics to achieve a good in-plane auxetic effect along both the wale and course directions. Although a number of auxetic fabrics have been developed and studied, most of the research are limited to auxetic behavior under a single tensile test. Only a few studies have been conducted on the auxetic behavior of fabrics under repeating tension. Wang and Hu first studied the auxetic behavior of warp knitted spacer fabrics under 10 repeating tensile cycles [16].

Their study showed that the auxetic effect decreased in the first several tensile cycles and then tended to remain constant. Kamrul et al. studied the auxetic behavior of woven fabrics based on reentrant and foldable geometries in five different directions under 20 repeating tensile cycles [28,29]. They found that the negative Poisson's ratio decreased with the increase of tensile cycles and the negative Poisson's ratio in the weft and warp directions showed better resilience to repeating tension. It should be pointed out that the previous studies are only limited within a small range of tensile cycles, which may not completely reflect the auxetic behavior of fabrics in daily use, because when those auxetic fabrics are used in daily life, it is more likely that they will be subjected to more instances of repeating loads. Therefore, study of the auxetic behavior of fabrics in a wider range of tensile cycles is necessary. In the previous study, a novel type of auxetic warp knitted fabric has been developed and its auxetic behavior studied in both the course direction and wale direction under a single tensile test [20]. The study has been extended to the auxetic behavior of fabric under repeating tension within a much wider range of tensile cycles. We hope that this study can offer useful information to improve the auxetic stability of auxetic fabrics for practical use.

The auxetic warp knitted fabrics were fabricated with three types of yarn: elastic yarn, polyurethane (PU) yarn wrapped by polyester yarn); binding yarn; and stiff yarn, The auxetic behavior has been determined in the wale and course directions. During the warp knitting process, elastic yarns were let-off with tension from the warp beams to the knitting zone. Due to their low modulus, they were extended very easily with applied tension during the knitting process. When all the tension was released after knitting, the extended elastic underlaps shrank, causing the rotation of diagonal ribs to form re-entrant structures. When stretched in the wale direction, the diagonal ribs tend to turn along the tensile direction, causing the expansion of elastic underlaps and, as a result, the fabric exhibits an auxetic behavior. The following procedures have been followed:

a) Preparing the fabric samples.

b) Repeating tensile test and calculation of the Poissons ratio.

c) Calculation of residual deformation in each cycle

Conclusion

The auxetic behavior of warp knitted fabric under repeating tension was studied. Its deformation process both in the wale and course directions was analyzed and the effect of residual deformation on the auxetic behavior of the fabric was discussed. The following conclusions can be drawn from this research. The fabric proposed shows good auxetic stability under the given test condition. Even after 100 instances of stretching with a tensile strain of 25%, the fabric can still keep an auxetic effect in both the course and wale directions.

a) The auxetic effect in the wale direction is higher than that in the course direction but has less auxetic stability. The underlaps formed with elastic yarns contribute to the better auxetic stability in the course direction due to lower residual deformation.

b) The residual deformation mainly comes from yarn transfer among loops and the yarn extension. The use of elastic yarns can reduce the residual deformation of the fabric under given tensile strain and, thus, increase the stability of the auxetic behavior. Despite good results being obtained in this research with a repeating tensile test of 100 cycles, the long-term durability of the auxetic fabric still remains unknown. Considering that most previous researches on the auxetic property of fabrics mainly focused on a single tensile cycle test, this paper can provide a reference value for the short-term auxetic persistence of fabrics. At the same time, it may also offer a reference for the long-term durability of auxetic warp knitted fabrics in future studies.

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