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Tribological properties of auxetic and conventional polypropylene weft knitted fabrics

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ABSTRACT

Purpose: The wear resistance and friction reducing properties of polymer fibres can be improved with negative Poisson's ratio behaviour. Poisson's ratio is defined as the ratio of transverse contraction strain to longitudinal extension strain in the direction of stretching force. Large number of materials have positive Poisson's ratio, however there are some materials which exhibit negative Poisson's ratio, they are termed auxetic materials. Auxetic materials present unique property that they expand in all directions when they are stretched and contract when compressed. This paper has highlighted, compared and discussed the variation between the modelling, theoretical and practical differences of auxetic materials wear behaviour.

Design/methodology/approach: For the purpose of this work, auxetic and conventional fibres were produced by the melt spinning mechanism using extruder. The fibres physical properties were evaluated such as Poisson's ratio, fibre count, elongation, force and tenacity. Mono-filament fibres were used for fabrication of weft knitted fabrics; plain (1x1) structure was employed for knitting fabric. The wear resistance of the knitted fabrics were tested by using Nu-Martindale Abrasion and Pilling Tester and comparison were made.

Findings: The abrasive wear test results demonstrated that the auxetic based weft knitted fabrics have superior wear behaviour than the conventional fibre based weft knitted fabrics.

Practical implications: The experiment showed that the auxetic material is capable of sustaining large amount of abrasion compared to conventional fabric.

Originality/value: The paper compare and discuss the variation between the modelling, theoretical and practical differences of auxetic materials wear behaviour.

Keywords: Abrasive wear; Auxetic materials; Weft knitted fabric; Poisson's ratio

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SHORT PAPER

1. Introduction

Polypropylene (PP) has various applications including technical textile products and composite structures because of its unique properties, such as high tensile strength, low cost, ease of processing and inert nature in addition; it is regarded as a thermoplastic polymer. PP has potential to make new materials and it is currently the fastest growing man-made fibre for different technical textile applications [1-3].

In technical textile applications, tribological properties of materials are one of very important practical characteristic, as mentioned in the various papers that have been studied on abrasion properties of textile materials, including some modelling researches. In this case, it is accepted that auxetic materials should have improved abrasion wear resistance and enhanced fracture toughness.

Auxetic PP fibre is one of the novel approaches for producing a material with a negative Poisson's ratio. Poisson's ratio is defined as the ratio of transverse contraction strain to longitudinal extension strain in the direction of stretching force. Large number of materials exhibit positive Poisson's ratio, however there are some materials which display negative Poisson's ratio, they are termed auxetic materials [4-7].

1.1. Auxetic materials wear resistance properties

The relationship between shear modulus (G), Young's Modulus (E) and Poisson's ratio (V) for isotropic materials is:

$$G = \frac{E}{2(1+\nu)} \quad (1)$$

As the Poisson's ratio approaches -1, the material becomes difficult to shear. Also the hardness (H) is related to Poisson's ratio as:

$$H\alpha(1-\nu^2)^{-x} \quad (2)$$

where (x) is a value which depends on the type of indentation. Equation 2 demonstrates that hardness will be enhanced for an auxetic material ~ -1. This enhancement is also shown schematically in Fig. 1.

Abrasive wear occurs when a material is being worn away as a result of rubbing or frictional contact. Adhesive wear occurs when a hard rough surface slides across a softer surface. It is suggested that, auxetic material should have improved abrasion wear resistance due to enhanced fracture toughness. In the case of adhesive wear, Archard [8] proposed that wear rate (displacement per unit time) Δh for general applications could be given in the following expression (Equation 3), where (Δh) is the wear displacement, (t) is the sliding time, (k) is the wear coefficient, (H) is the hardness of tested material, (P) is the applied pressure and (V) is the sliding speed:

$$\Delta h = \Delta ht = kHPV \quad (3)$$

Enhanced adhesive wear resistance is, therefore, expected in auxetic materials by virtue of their enhanced hardness potential. Improved wear resistance causes an enhancement in the abrasion resistance such as ropes, cords and fishnets. Being resistant to abrasive wear should also be useful in other fibre applications where abrasion occurs, such as upholstery fabrics for furniture and automotive seats. Therefore, it is suggested that the enhanced wear resistance of auxetic materials should enhance the performance of materials and their life of usage [9].

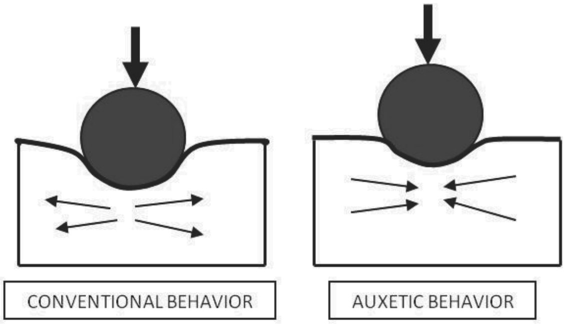


Fig. 1. Indentation resistance of auxetic by comparing to conventional structures

2. Experimental details

2.1. Materials

The auxetic and conventional PP fibres were manufactured from Coathylene PB0580 powder, produced by DuPont Polymer Powders (Sarl, Switzerland) and supplied by Univar (Bradford, UK). The PP powder has a rough surfaced with an average particle size of ~50 μm and melting range 159-171°C. A lubricant was used as a paraffin which provided by Unicorn Chemicals Ltd. (Blackpool, UK).

2.2. Fibre fabrication

Auxetic and conventional PP fibres have been produced by the melt spinning technique using previously established processing parameters. The single screw extruder consisting of an Archimedean type screw is used to produce fibres which common type of melt extruder for polymers. The barrel can be heated over a wide temperature range generally between 150°C and 300°C. The melt extruder consists of a hopper, screw and a die or spinneret. The extruder screw assists in conveying the material through the extruder imparting the energy to melt the polymer and mix the polymer uniformly [10], which also pumps the molten polymer at a constant rate. The polymer material then passes through the die, which consists of a spinneret. The spinneret has variable thickness and size, which are usually circular and made of special stainless steel. The main function of the die is to give the required shape to the extruded polymer. Finally, the fibre undergoes orientation and subsequent heat treatment processes before it take up bobbins in Fig. 2. [11,12,13].

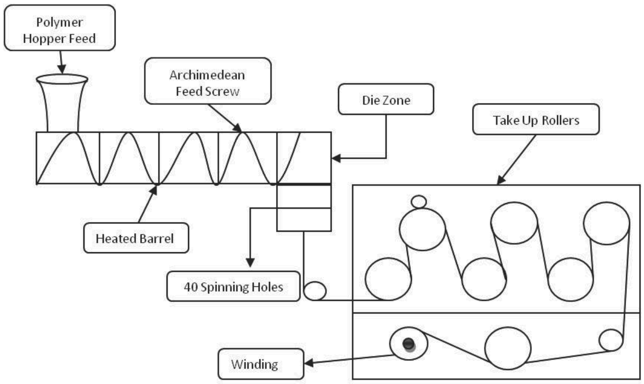


Fig. 2. Melt spinning extruder [13]

Melt Extruder Set up

A continuous melt extrusion process has previously been developed to produce the first known auxetic material in fibre form. A melt spinning process was performed using a melt extruder consisting of an Archimedean type screw with 3:1 compression ratio, 25.4 mm screw diameter, and thermostats for each of five temperature zones. Powder was fed through a hopper into the barrel and fed through the extruder by the action of the screw, with a flat temperature profile of 159°C in all zones of the extruder for auxetic PP fibre production. The extruder was operated at a 10 rpm (1.05 rad.s−1) screw speed and 2 mpm (0.03 m.s−1) take-up speed and a 40−filament die with each hole having a diameter of 550 μm was fitted. The extruded fibres were cooled in air after exiting the die before winding on the rollers.

2.3. Knitted fabric production

Plain fabric has been chosen for the knit fabric structure, the fabric consisting wholly of knitted loops which are all meshed in the same direction (Fig. 4) [14]. The auxetic fibres were cured with lubricant for extra slipperiness for 4 hours, after curing process filament samples were conditioned for 24 hours at atmospheric conditions, 20°C and 65% Relative humidity. It was found that curing with lubricant does not affect the physical properties of filaments. The knitted fabrics were fabricated from PP mono-filament and were knitted by a manual flat V-bed knitting machine. Plain knit structure was produced using in total 140 needles (70 in front-70 at back and 7 per/inch) in Fig. 3 [15,16].

2.4. Videoextensometry

Characterisation of the fibres was carried out using a MESSPHYSIK ME 46 video extensometer in combination with a micro tensile testing machine in order to examine the auxetic behaviour of the fibres. A software package was developed by Messphysik GmbH that measures strains and/or extensions on standard specimens. The videoextensometry was used to measure the strains in both axial and transverse directions, and hence the Poisson's ratio of the fibres was determined.

The microscopic structure of the fibres was studied using SEM and a comparison of the structures of the auxetic and conventional fibres were made. Mechanical testing including Poisson's ratio determination, Young Modulus determination and tensile strength of both auxetic and conventional fibres were also investigated.

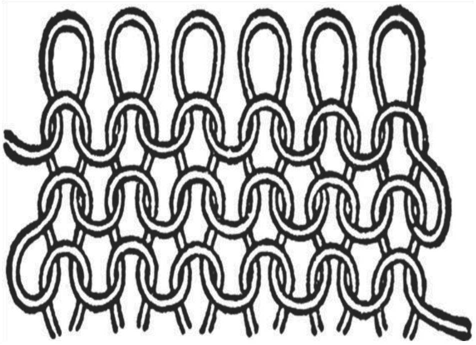


Fig. 3. Plain knitted structure sample

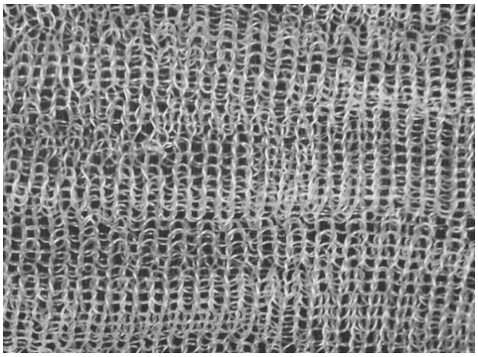


Fig. 4. Plain knitted fabric

2.5. Abrasive wear testing

The test was performed using Martindale Abrasion Tester, see Fig. 6, using the established standard Martindale abrasion method [17,18]. Abrasive wear testing covers the determination of the resistance to abrasion of textile fabrics using the Martindale abrasion tester. The measurement of the resistance to abrasion of textile fabrics relies on several parameters such as the mechanical properties of the fibres, the dimensions of the fibres, the structure of the yarns, the construction of the fabrics and type, kind, finishing material etc. [19,20].

Firstly the test specimens were prepared with press cutters, after those specimens were conditioned for 24 hours using relative humidity of 65% and temperature of 20°C. The knitted fabric samples were cut into circular samples of 38 mm in diameter and placed on the sample holder, see Fig. 6. The test was performed using pressure of 9 kPa, and the machine speed was maintained at 50 rubs per minute until total of 5000 rubs were completed, which equates to 10 minutes per sample cycle. After performing every 5000 rubs, samples were inspected for abrasion. The endpoint was determined by a specified number of cycles or when a hole appears in the test area.

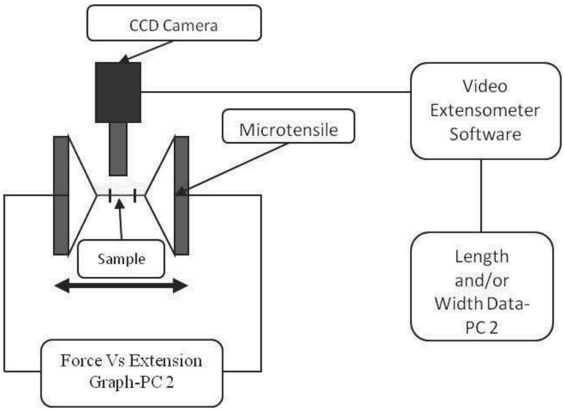


Fig. 5. Videoextensometry working principle [13]

3. Result and discussion

3.1. Measurement of mechanical properties of fibres

The Table 1 shows the fibre count, elongation, force, tenacity and Poisson ratio values under room temperature. The physical properties of both fibres were determined by Fafegraph M and test parameters were gauge length 100mm, load cell 10 N, test speed 200 mm/min and preload of 0.50 cN/tex.

As shown in Table 1, auxetic fibres Poisson ratio is between -0.70 to -0.40 however conventional PP fibres have better physical properties than auxetic fibres.

3.2. Knitted fabric abrasive volume

Auxetic and conventional fabrics wear were performed for 12 different samples and comparison were made. Each of the samples was inspected for abrasion properties after every 5000 rubs. After the initial 5000 rubs, both fabrics did not exhibit any significant wear. The Fig. 7A-C, shows conventional PP fibre based knitted fabrics, Fig. 7D-F and Fig. 8G-H shows auxetic PP fibres based knitted fabrics after conducting abrasion experiment. The results indicates that there is no significant abrasion wear for conventional and auxetic fibres when subjected to 10000 rubs, however, the conventional fibres showed some minor weak points. However, after 15000 rubs, the conventional fibre showed signs of determination, whereas the auxetic fibres maintained its abrasion resistance properties. After 20000 rubs, the conventional fabrics was rendered useless, however, the auxetic material retained large proportion of integrity. After 25000 rubs the auxetic fabric began to show signs of weak points, but it was not until 30000 rubs that the material was completed rendered useless. The experiment showed that the auxetic material is capable of sustaining large amount of abrasion compared to conventional fabric.

Table 1.
Fibre properties

	Auxetic (159°C)	Conventional (170-230°C)
Fibre count (Tex)	40	40
Elongation (%)	2.17	4.66
Force (cN)	127.54	92.81
Tenacity (cN/Tex)	3.19	2.32
Poisson's ratio values	-0.70 to -0.40	-0.12 to +0.35

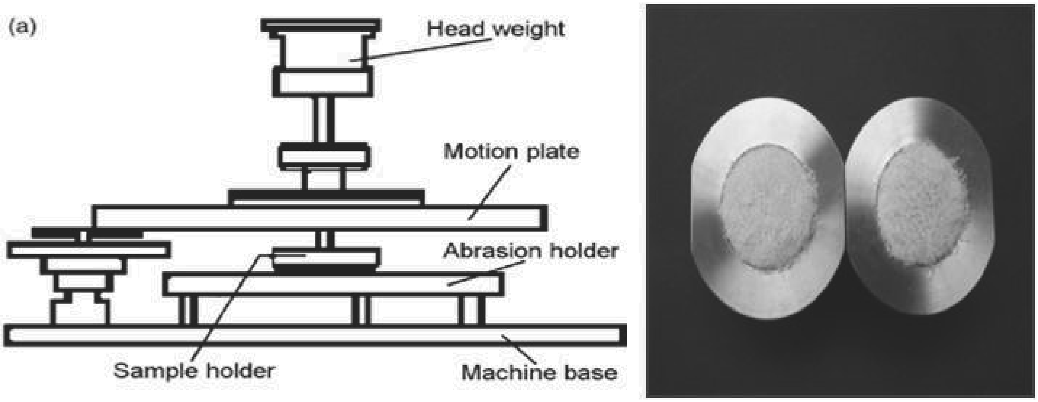
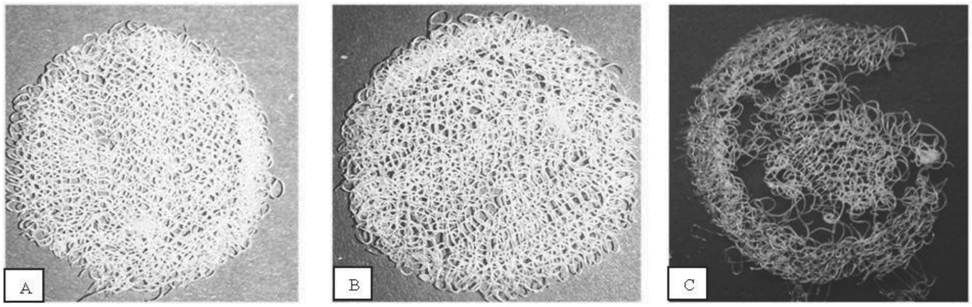
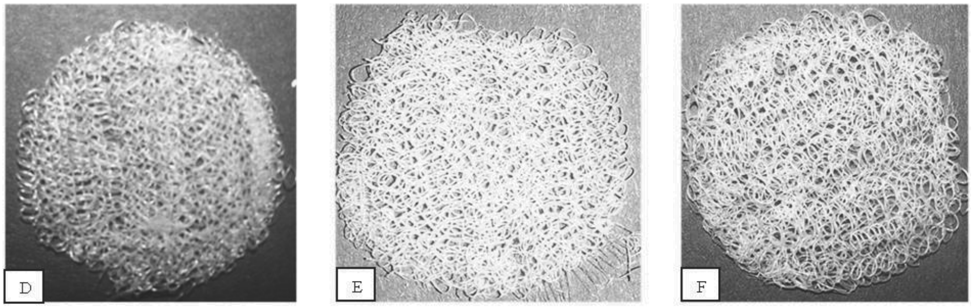


Fig. 6. Martindale abrasion tester and tample holder [17]

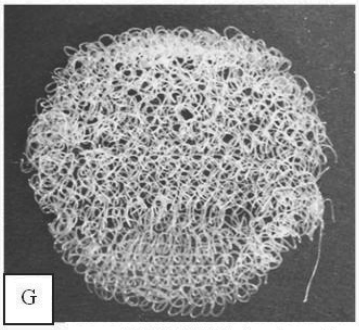


(A) 10000 Rubs Conventional (B) 15000 Rubs Conventional (C) 20000 Rubs Conventional

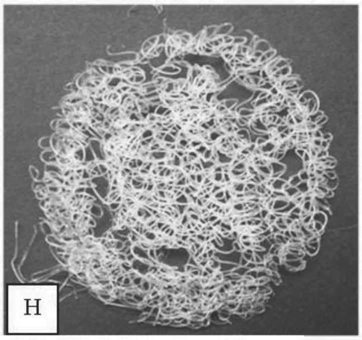


(D) 10000 Rubs Auxetic (E) 15000 Rubs Auxetic (F) 20000 Rubs Auxetic

Fig. 7. Photograph of conventional and auxetic PP based knitted fabrics after abrasion



(G) 25000 Rubs Auxetic



(H) 30000 Rubs Auxetic

Fig. 8. Photograph of conventional and auxetic PP based knitted fabrics after abrasion

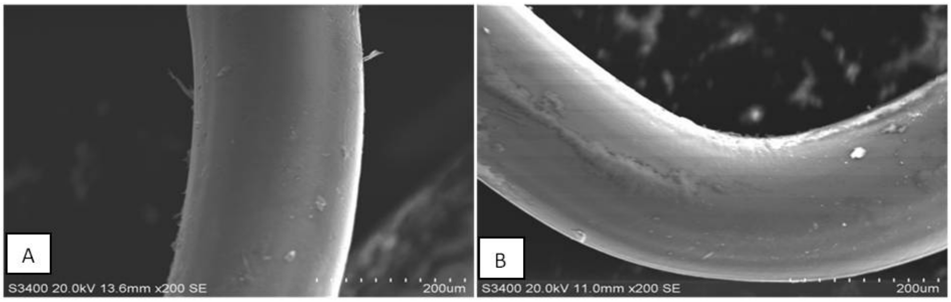
3.3. Scanning electron microscopy studies

The phase morphological characteristics of the samples were observed by SEM (HITACHI S-3400) in the normal mode and all the fibre samples were fixed by adhesive tape in the sample stage and coated with gold by Sputter Coater (SC 7620). From the results shown in Fig. 9, it can be confirmed that auxetic PP fibres surface after abrasion evaluation indicates lesser damaged fibres than conventional fibres.

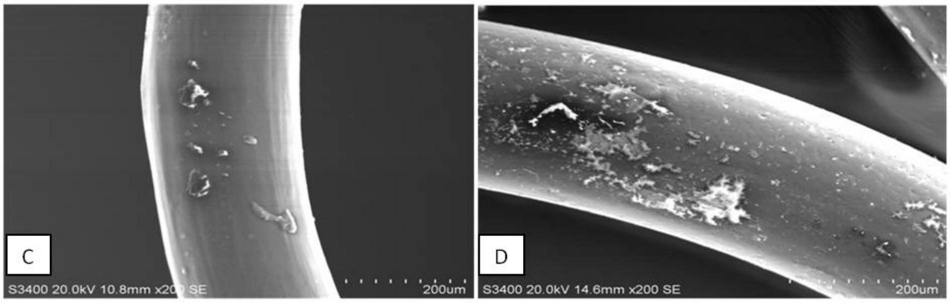
4. Conclusions

The above results and discussions suggest following conclusions:

1. Tensile properties of the auxetic PP fabric, which were manufactured with temperatures of 159°C are comparable to that of conventional PP which were manufactured with temperatures of 170°C-230°C. Auxetic fibre possessed reasonable tensile properties, however, it appeared to be fragile during knitting process, and as a result, the fibres had to be pre-cured with lubricant to evaluate fibre breakage.
2. Finally, the abrasion resistance of both the auxetic and conventional PP fibre based knitted fabrics have been compared which showed that auxetic PP knitted fabric has better abrasive wear resistance (15-35%) than conventional PP knitted fabric (produced at 200°C and over).



(a) Auxetic PP after knitting process (prior to abrasion) (b) Conventional PP after knitting process



(c) Auxetic PP after abrasion testing (b) Conventional PP after abrasion testing

Fig. 9. SEM images of auxetic and conventional PP fibres surface (×200)

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