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Study of Properties of Medical Compression Fabrics

Lijing Wang [a,*], Martin Felder [a], Jackie Y. Cai [b]

[a] *School of Fashion and Textiles, RMIT University*
25 Dawson Street, Brunswick, Victoria 3056, Australia

[b] *CSIRO Materials Science and Engineering PO Box 21, Belmont, Victoria 3216, Australia*

Abstract

Compression garments apply pressure to the body to provide health benefits, such as increasing the blood circulation, shaping the body and supporting healing after medical procedures. Fabrics used for compression garments are elastic, and the amount of fabric stretching and the ability of maintaining the stretching force are directly related to the compression effectiveness. However, there is currently little information about the fabric and its mechanical properties, and there is a demand from compression garment manufacturers to better understand the fabric properties and their serviceability. This paper studied the physical and mechanical properties of 4 Nylon/Spandex knitted fabrics as commercial medical compression garments. In particular, fabric elasticity and bursting strength were examined to demonstrate the applicability of the fabrics for providing satisfactory compression. It was observed that the compression garment fabrics had an open knitted structure with stable dimensions, and Spandex was only present in the wale direction. Tensile assessment revealed that the compression fabrics were strong and their breaking extension was well beyond 200%. The fabric stretching force had a near linear relationship with its elongation when the fabric was stretched upto 100% extension. After fatigue stretching, the average immediate recovery of compression fabrics examined was more than 95% and the average elastic recovery after an extended period of relaxation was at least 98%. High fabric bursting strength and compression extension were also found. The results of fabric physical and mechanical properties from this study are very important for understanding whether a fabric is suitable for engineering compression garments, and also for estimating the required compression force for designing an individualised compression garments with the medical compression fabrics.

Keywords: Compression Garment; Bursting Strength; Stress Relaxation; Elasticity; Fabric

1 Introduction

Compression garments are special garments that apply a certain pressure to the body mainly for medical [1-5], sports [6,7] and body shaping [8] purposes. Compression garments have been used in the medical field to treat burns (scar management), low blood pressure, muscle strains and sprains. They have also been used to accelerate the healing process and prevent deep vein thrombosis during long haul flights.

*Corresponding author.
Email address: lijing.wang@rmit.edu.au (Lijing Wang).

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After a burn injury has healed, the skin often scars as a result of collagen production, and becomes hard and dark coloured. It is believed that applying pressure using a compression garment helps to flatten the scar, though there might be insufficient evidence to support the widespread use of pressure garment therapy for the prevention of abnormal scarring after burn injury [9].

Compression garments have also been used to provide compression on the body's muscles to increase the blood flow, which improves performance, reduces the risk of injury, and accelerates muscle recovery during and after exercise. Hence the use of a compression garment, in particular a gradual compression garment, in sports activities is becoming a popular trend, and many professional players and athletes already wear compression clothing on a regular basis. Increasingly, compression garments are also used as shapewear to enhance body image, such as creating attractive contours, lifting breasts, and reducing abdominal size. They are worn under normal loose-fitting clothing.

Most medical compression garments are individually designed and manufactured for a particular part of the body, such as stockings, gloves, sleeves, face masks and body suits. They are worn for an appointed time, depending on the medical treatment need.

The circumference of a compression garment is smaller than the body size. When in use, the garment is stretched, providing optimum compression. Depending on needs, special garments are also used to provide targeted compression on specific groups of muscles. The pressure usually exceeds the capillary pressure, 24 mmHg, though a low level of compression (5–15 mmHg) can also achieve good clinical results [10].

The level of compression is governed by the garment size as well as the amount of fabric stretching. Fabrics for compression garments are usually engineered with stretchable structure and containing elastomeric material to achieve highly stretchable and appropriate compression.

Elastic recovery is the most important performance indicator for compression garments. When a fabric is stretched to a level below its breaking strength and is then allowed to recover, the fabric normally does not immediately return to its original shape. Its elastic recovery depends on the compression force provided, the length of time that the force is applied for, and the length of time that the fabric is allowed for recovery.

Each compression garment is required to last for at least several months. As an example, compression garments for preventing hypertrophic scarring after severe burns may be worn for up to 2 years. Fabric fatigue occurs when a fabric is repeatedly stressed at a force level less than that needed to cause failure in a single application. For compression fabrics, the residual extension should be as small as possible after fatiguing. It is therefore essential that compression garments maintain good durability and do not stretch out of shape after repeated wear and laundering. This paper aims to assess and better understand the mechanical properties of some knitted compression fabrics used for making long lasting compression garments.

2 Experimental

2.1 Fabrics

The Therapist Support Laboratory Pty. Ltd., a specialist manufacturer of custom made compression garments in Australia, provided 4 types of fabrics coded FT, BB, PN1 and PN2 for this study. They were used throughout this investigation.

2.2 Fabrics Elasticity Tests

Initial testing trials indicated that the tensile properties of strip fabric for compression garments can be measured like woven fabrics. Therefore, the compression fabric tensile properties were evaluated according to Australian Standard AS 2001.2.3.1-2001 (determination of maximum force and elongation at maximum force using the strip method). Strip specimens of 50±1 mm in width and the test speed of 100 mm/min were used. However, the gauge length was only 100 mm due to the high elasticity of the testing fabric. The fabric stretch-recovery tests were carried out according to BS EN 14704-1:2005 standard (determination of the elasticity of fabrics—strip tests). The strip width was 50±1 mm; gauge length was 100 mm and the test speed was 500 mm/min. Fig. 1(a) shows the experimental setup for the tensile tests.

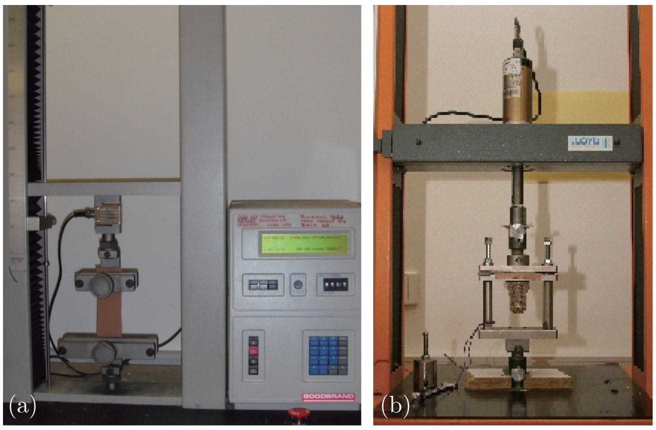


Fig. 1: Machine setup for strip fabric tensile tests (a); and fabric ball bursting strength tests (b).

Fabric long term elastic recovery performance was also evaluated by stretching a fabric band with a width of 115 mm to 25% on a PVC tube of 225 mm in diameter for 5 days and 21 days respectively. The fabric residue extension after stretching was calculated according to Equation (1).

$$\text{Residue extension (\%)} = \frac{L_1 - L_0}{L_0} \times 100 \tag{1}$$

Where: L_0 is the fabric length before a stretching test starts; and L_1 is the fabric length after testing.

2.3 Bursting Strength Tests

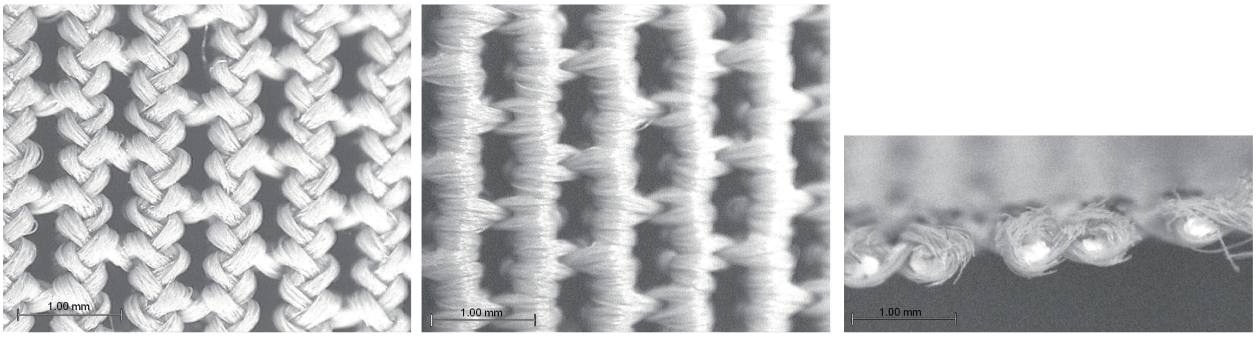
The ball burst method was used to determine the bursting force of compression fabrics following Australian Standard AS 2001.2.19 (determination of bursting force of textile fabrics-ball burst method). Fig. 1(b) shows the experimental setup for ball bursting strength testing. The tests were performed on the Lloyd instrument. The compression rate was set at 300 mm per minute, and the polished steel ball was 25 mm in diameter. After clamping, a fabric area of 45 mm in diameter was compressed by the steel ball.

All tests were performed on specimens conditioned under 65±2% r.h. and 20±2°C environment in their relaxed state.

3 Results and Discussion

3.1 Fabric Analysis

Observation with a microscope revealed that all fabrics have a knitted structure and Spandex is only present in the wale direction. All fabrics have the same construction pattern, and Fig. 2 shows the structure of fabric PN1 as an example.



Face Back Cross-section

Fig. 2: Structure of compression fabric PN1 under the microscope.

Generally, the face side of the fabric has raised wales while the back side is smooth. A flat fabric back surface would reduce stress concentration upon compression and also provide a comfortable smooth surface to contact with the skin. The compression force is usually produced through one dimensional fabric stretching, which means that the wale direction with Spandex is normally used for producing effective pressure in compression garment design. Table 1 lists the fabric thickness,

Table 1: Fabric information and properties

Fabric code	Properties	Value
	Nylon/Spandex	75/25
BB	Thickness (mm)	0.48
	Area density (g/m^2)	102
	Nylon/Spandex	72/28
FT	Thickness (mm)	0.49
	Area density (g/m^2)	206
	Nylon/Spandex	67/33
PN1	Thickness (mm)	0.53
	Area density (g/m^2)	240
	Nylon/Spandex	63/37
PN2	Thickness (mm)	0.61
	Area density (g/m^2)	313

area density and fibre composition. It can be seen that the fabric contains 25% or more Spandex. Its thickness is around 0.5 mm and area density varies from 102 to 313 g/m^2. Further fabric assessment revealed that all fabrics were open and dimensionally stable.

3.2 Tensile Behaviour

Since the compression fabrics contain a high percentage of Spandex and are very elastic, it is not common for the fabrics to be stretched to breaking point during tensile assessment. However, in order to understand the maximum breaking force of the fabrics, strip specimens of 50 mm in width were stretched to break. It was found out that all specimens have a breaking load greater than 200 N and breaking extension well beyond 200%, especially in the wale direction. This suggests that the compression fabrics are strong and have excellent stretchability.

The load-elongation curves in Fig. 3 (a) show that at the same extension level, the stretching force is higher in the course direction than in the wale direction. This is due to the special fabric structure design, where Spandex filaments are used in the wale direction (Fig. 2). At the initial stretching stage (upto approximately 150% extension), the fabric structure allows large deformation and the extension of Spandex mainly bears the load. It can also be seen in Fig. 3 that the relationship between load and extension is almost linear when the fabric is stretched to upto 100% elongation. For a compression garment, it is rare for its constituent fabrics to stretch more than 70%. The relationship in Fig. 3 provides the convenience to predict the level of compression required, and design gradual compression garments by selecting the right material and fabric length.

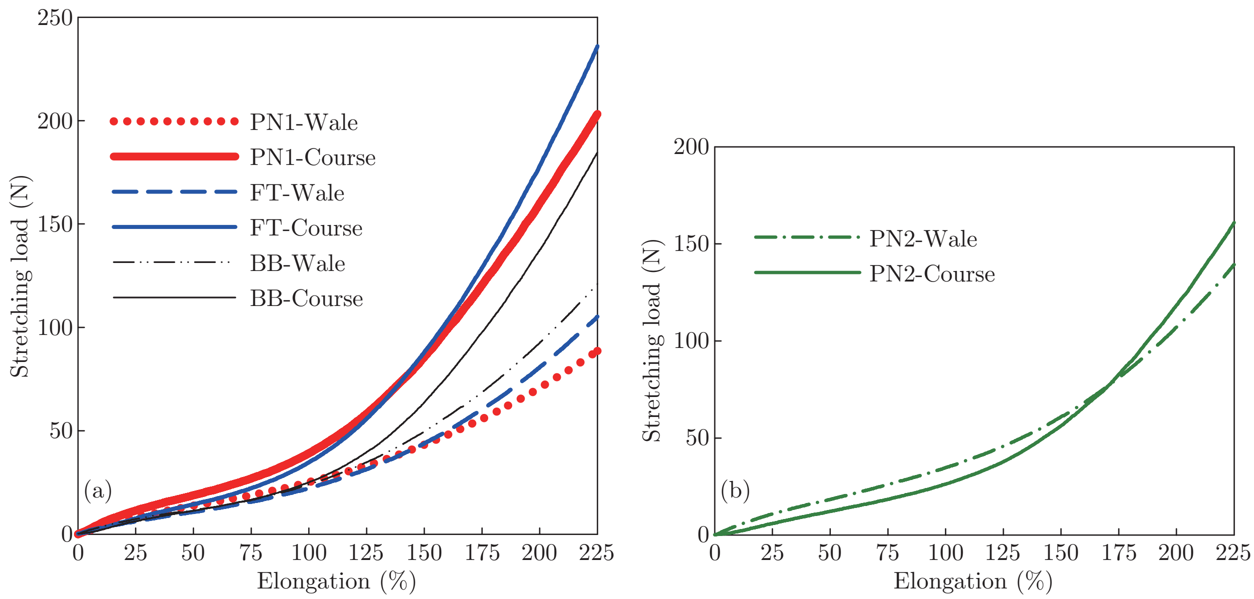


Fig. 3: Typical stretching force-extension curves in wale and course directions.

Though Fig. 3(b) shows that the stretching force is slightly lower in the course direction than in the wale direction during the initial extension, the course direction stretching force becomes higher after approximately 170% elongation, following the same trend as Fig. 3(a). As the Spandex provides gentle and linear stretching force, during garment design and engineering, the wale direction is preferred to provide required compression.

3.3 Elastic Recovery

After fatigue cycling the specimen twice along the wale direction between zero extension and the specified force of 30N at a speed of 500 mm/min, the average immediate recovery values for PN2 and BB were 99.5% and 98.5%, respectively. Experimental results also revealed that other compression fabrics examined also had good stretch and recovery performance. In the wale direction, after fatigue cycling the specimen twice between zero extension and the specified force of 50N, the average immediate recovery was more than 95%, and the average elastic recovery after an extended period of relaxation (1–24 hours) was 98% ∼ 100%. Under the same testing conditions, in the course direction, the average immediate recovery was similar to the wale direction. However, the stretchability was low and a small residue extension may exist after relaxation.

The elastic recovery performance of PN2 and BB fabrics was further evaluated by stretching the fabric bands to 25% elongation for 5 days. The results in Fig. 4 show that the immediate recovery for both fabrics is more than 96%. After an extended period of relaxation (e.g. 1–4 hours), their average residue elastic recovery is less than 2%.

After 21 days of stretching the PN1 fabric, the fabric's average immediate residue extension was nearly 4% as shown in Fig. 5. However, a few hours relaxation allowed the fabric to quickly recover, resulting in the residue extension to be around 2%. Therefore, it is reasonable to believe that compression garments from the fabrics examined should maintain good serviceability at around 25% extension. Hence the fabrics are suitable for compression garment materials in terms of stretch and recovery.

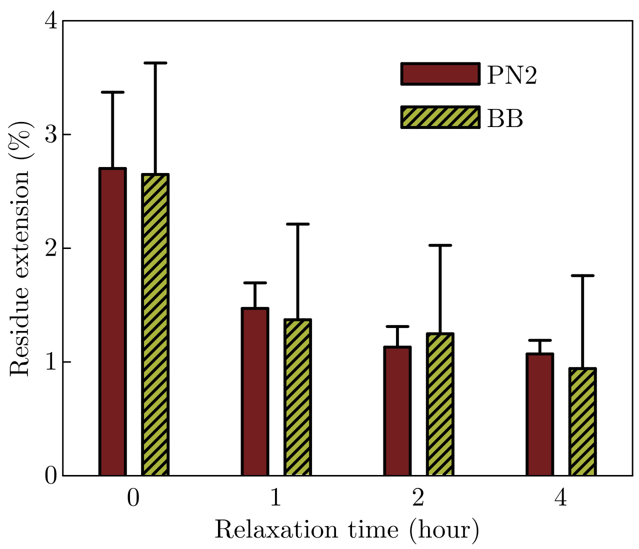


Fig. 4: Residue extension after 5 day stretching.

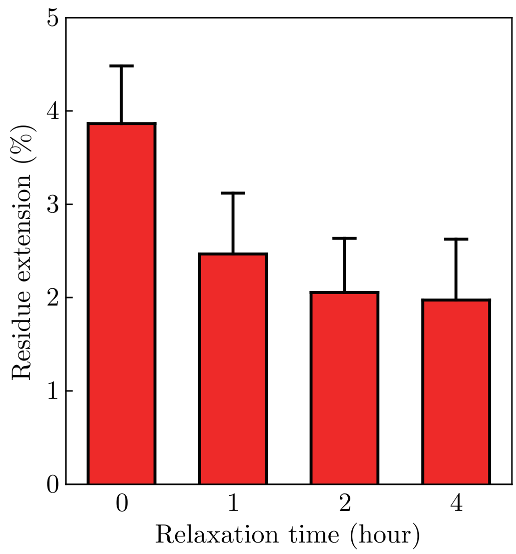


Fig. 5: Residue extension after 21 days stretching of PN1 fabric.

3.4 Bursting Strength

Strip fabric tensile strength tests are generally used for woven fabrics where there are definite warp and weft directions to produce the required sample width, while bursting strength is an alternative method of measuring strength in which the material such as knitted fabrics is stressed in all directions at the same time. Though the knitted compression fabrics have distinct wale direction and fabric integrity after cutting for strip fabric tensile tests, bursting strength tests were carried out for the fabric bursting performance assessment.

The compression load – extension curve in Fig. 6(a) shows that the fabric FT stretched beyond 40 mm before bursting and the bursting force increases rapidly with the extension. It was observed that some fabric specimens were so strong and elastic that they may not burst even after 50 mm compressing extension, in particular fabrics PN1 and PN2, which have a high percentage of Spandex. Fig. 6(b) shows that the bursting strength is greater than 200 N for all fabrics, and fabric PN2 is the strongest and fabric BB is the weakest. The difference in bursting strength reflects to the fabric thickness and area density (Table 1). The diverse fabric properties including bursting strength, compression extension and thickness and weight are important characteristics for engineering different compression garments.

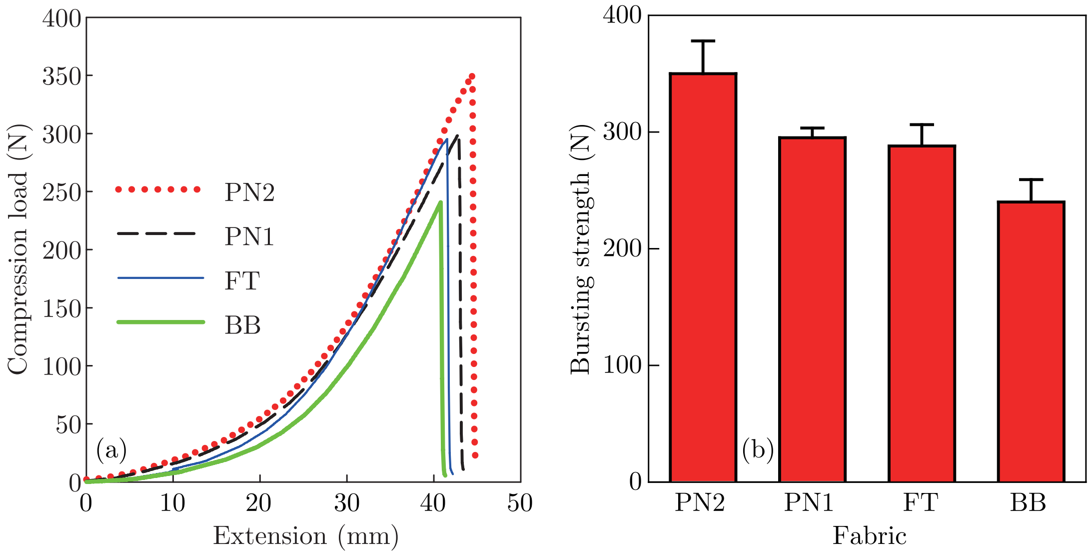


Fig. 6: Typical bursting strength testing curves (a) and bursting strength (b) of different compression fabrics.

4 Conclusion

This paper studied the properties of medical compression fabrics made from Nylon/Spandex. The fabrics are knitted with an open structure with stable dimensions, and Spandex is only present in the wale direction. Tensile assessment revealed that the compression fabrics are strong with a breaking load greater than 200 N, and have excellent stretchability with breaking extension well beyond 200% in both wale and course directions. The fabric stretching force is proportional to extension when the fabric is stretched to under 100% elongation. The fabrics also have high bursting strength and extension that are well equipped for use as compression garments. After fatigue stretching, the average immediate recovery of compression fabric is more than 95% and the average elastic recovery after an extended period of relaxation (1–24 hours) is at least 98%. After 3 week service and a few hours relaxation, the compression fabric has only around 2% residual extension.

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