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The Effect of Fabric Constructions on Elastic Behaviour and Tension Decay of Compression Garment

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Abstract. Knitted fabrics used as compression garments are subjected to deformation due to various loads used to extend the fabrics during wear. The loads to extend the fabrics are influenced by fabric constructions, strain levels and fabric directions. This study investigates the elastic behaviour and tension decay of different knitted fabrics at different strain levels. The strain of fabrics was measured using a tensile testing machine, and each sample was cycled five times between zero and the specified strain to simulate the repeated use of compression garments. The elastic behaviour and the tension decay were evaluated in both length (wales) direction and width (course) directions of the fabrics. It was found that fabric constructions, strain levels, and fabric directions have a significant impact on the fabric load and the tension decay of fabrics ($p<0.05$).

INTRODUCTION

Compression garments are mainly used for medical, sport and body shaping purposes. In the medical field, compression garments are used for scar management of burn patients, orthopaedic support and management of arthritis disease [1, 2, 3, 4, 5, 6]. Most medical compression garments are designed and manufactured for specific parts of the body, such as stockings, gloves, sleeves, and bodysuits. They are worn over a specified time, depending on the need for medical attention [6]. Due to their elastic nature, they are generally used to provide a certain amount of pressure on the body parts as a simply applicable therapy method [7]. Some advantages of compression garments are to improve blood flow, better muscle oxygenation, reduce fatigue, faster recovery, reduce muscle oscillation and reduce muscle injury has been reported for most of the compression garments available in the market for sport applications [7]. In the sports field, it has become a popular tool for athletes to enhance performance in competition, reduce post-exercise trauma, reduce muscle soreness and reduce recovery time after exercise and training [8-11]. These advantages were reported based on the fact that the compression garment is used as an application of principle aerodynamics to reduce drag in high-speed sports, resist the impact force of muscle caused during running or jumping, thus decreasing unnecessary muscle vibration and applying pressure on specific muscle to increase blood flow [12,13].

To apply a certain amount of mechanical pressure and be tightly fitted on the human body, fabrics for compression garments are usually engineered with stretchable structure and containing elastic material to achieve highly stretchable and appropriate compression [2]. During wearing, compression garments extend depending on the reduction factors designed and remain in the extended state while worn, thereby exerting some pressure on the wearer's hand [14]. Compression garments are 10 to 20% smaller than the actual hand circumferential dimensions in accordance with fabrics extensibility [6,15]. The amount of reduction is called reduction factor. The common compression garments are made from weft knitted fabrics. Weft knitted fabrics are used due to their unique geometry, structural properties and mechanical behaviour [5,7]. Each of different constructions of the fabric has different physical and mechanical characteristics such as fabric weight, thickness, stretchability, and recovery. However, there is little information about the compressional behaviour of different weft knitted fabric construction as compression garments. Therefore, by understanding the elastic behaviour of different fabric construction, the pressure applied by compression garments can

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act as a reference for selecting suitable fabrics in developing compression garments. Compared to woven structure, the ability of knitted fabrics to stretch by stitch arrangement adds comfort characteristic. This is affected by properties such as extensibility, air permeability, and heat insulation of the garments made from knitted fabrics [16]. However, the majority of the fabrics will lose a considerable amount of their initial tension over time and lead to a decrease in applied pressure, thus making the garments less effective to the wearer [7,17]. The pressure applied by compression garments is determined by different factors including the fabric construction, physical properties, body texture and nature of the physical activity. Therefore, the elastic behaviour and the tension decay influence the pressure applied by compression garments performance.

In this study, the tensile behaviours and the change in fabric load to extend different knitted fabrics after repeated extensions were studied. Single jersey, rib, and terry structures were used in this study. These constructions are produced by different arrangements of loops in their course (widthwise) and wales (lengthwise) of the fabrics [18].

METHOD

Fabrics used for compression garments are usually knitted fabric and consist of elastane to provide elasticity and dimensional stability. Three knitted fabrics with different types of fabric structures were selected in this study. The weft-knitted fabrics are produced on a circular knitted machine using cotton yarn (30 Ne) and spandex yarn (40 Ne). The fiber content were made similar for all the fabrics to examine the impact of different fabric constructions on elastic behaviour and tension decay. The mass per unit area of each fabrics was measured in g/m^2 in accordance with ASTM D6242 Standard Method. The details of the fabric specifications and fabric structure diagrams are presented in Table 1.

TABLE 1. Fabric samples constructions and compositions

Fabric code	Fabric constructions	Fibre content	Fabric weight (g/m$^{2)}$
S1	Single jersey	95% cotton/5% elastane	268.55
R1	1x1 rib	95% cotton/5% elastane	263.76
T1	Terry	95% cotton/5% elastane	345.58

Investigation of Fabric Tension Decay

The fabric samples were cut to 290 mm x 75mm. Two gauge marks were marked on the sample which are 250mm x 75mm apart, approximately the same distance from fabric samples. Then, a loop was formed by folding the samples and the sample was sewed together along the gauge mark by using a single-needle stitch. The test sample was conditioned in the standard atmosphere which is 21 ± 1 0C & 65 ± 2% relative humidity at least 24 hours before testing. The fabric tension decay had been conducted using a commercial tensile machine namely LR30K Lloyd instrument in accordance with the standard test method for fabric tension and elongation (ASTM D4964). The samples were mounted onto the looped bars of the tensile machine manually under zero load and its position was adjusted around the bar so that the seam lay midway between the bars (Figure 1). The rate of extension and retraction of the specimen was set to 500 mm/min. To simulate the repeated use of compression garments, the samples were cycled five times between zero and the specified extension. After cycling five times, the load and strain level data was recorded. For every strain level, the test was repeated five times using different samples in both course and wales directions. The strain levels of 10%, 15%, and 20% were used in this experiment in accordance with the standard reduction factors used commonly for making compression garments as suggested by [18]. The tensile behaviours and the change in fabric load after repeated extensions in relation to the reduction factors had been done by investigation and observation of the load/strain curve. The percentage of tension decay was calculated, as per equation 1:

$$\text{Fabric tension decay} = (T_0 - T_1) / T_0 \times 100\% \quad (1)$$

Where:
T_0 = Tension of the original fabric (N)
T_1 = Tension of the fabric after 5 cycles of extension (N)

Analysis of variance was performed to determine if there were statistically significant differences among the means.

FIGURE 1. Looped fabric sample mounted on looped bar of tensile machine.

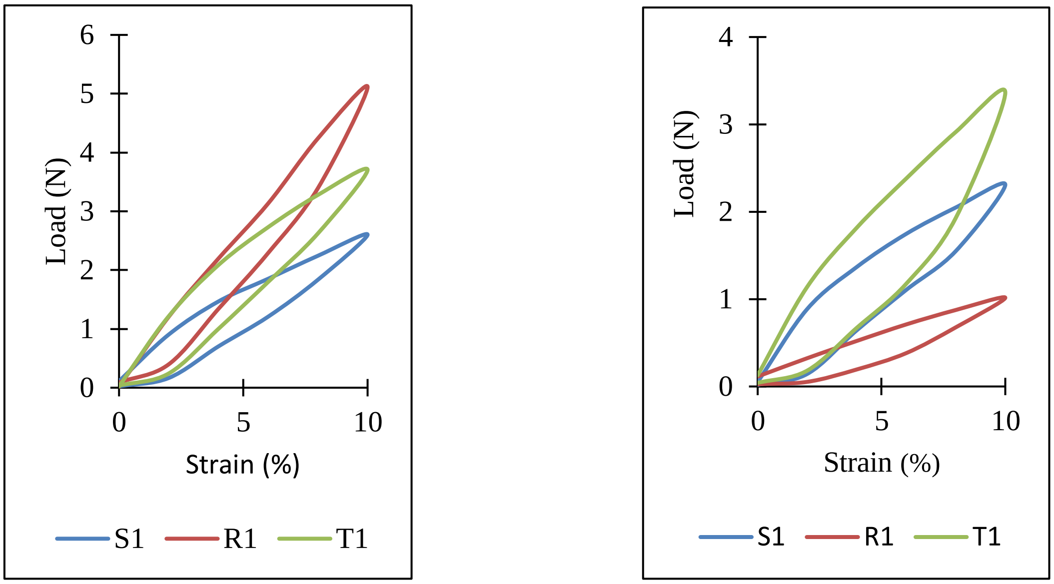
RESULTS AND DISCUSSIONS

From Table 2, It can be seen that different fabric construction has different load at 10%, 15% and 20% strain on both wale and course directions. It is obvious that the higher the strain level will cause a higher load in the fabric. This is the general physical property of elastic fabric. R1 recorded the highest load on wale direction while T1 recorded the highest load in the course direction. The load required to extend R1 at 10%, 15% and 20% strain in wales direction are 5.11 N, 7.81 N and 10.60 N respectively. At the same time, the load required to extend T1 at 10%, 15% and 20% strain in the course direction are 3.36 N, 4.93 N and 6.41 N respectively. In wales direction, the average load required to extend R1 compared to S1 is 74%. At the same time, the average load difference of R1 and T1 is 49%. While in course direction, the average load required to extend T1 compared to S1 is 47%. At the same time, the average load difference of T1 and R1 is 107%. The results indicate that R1 in wales direction and T1 in course direction will generate most pressure when extended and thus a greater pressure on the body of the patient wearing a compression garment of the same size made of this fabric. Inversely course direction, R1 required the lowest load to extend. This indicates that the R1 is much more elastic in course direction compared to S1 and T1. This could be explained due to the fact that rib structure has better course direction stretch properties than other knitted structures [19]. This is because fabrics with high extension properties need low load to extend and its strength decreases [20]. This shows that rib knitted fabric has the lowest load (N) to extend in the course direction than wales direction.

TABLE 2. Maximum load of fabrics at 10%, 15% and 20% strains on different direction

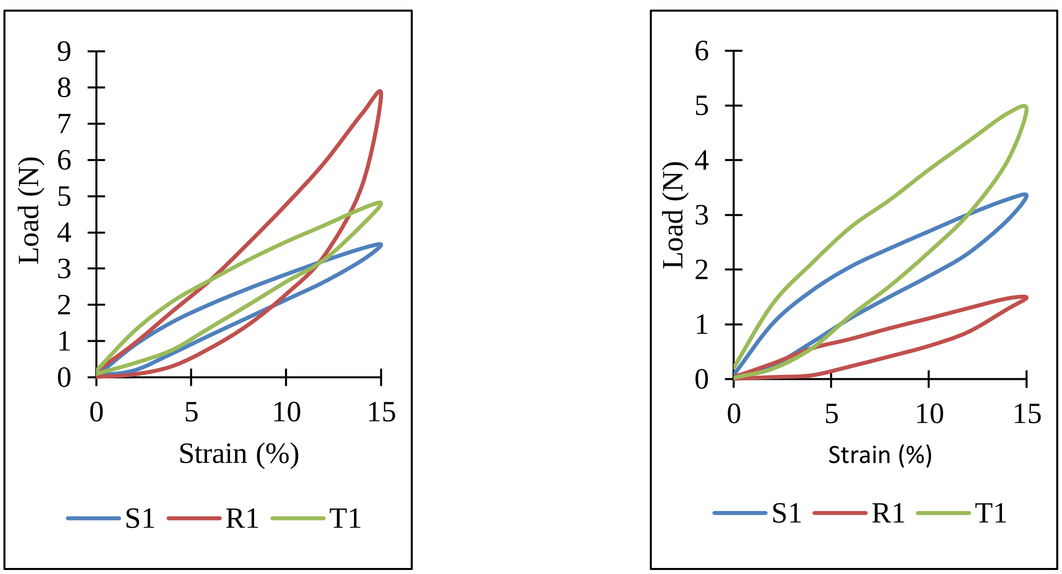
	Wale direction			Course direction		
	Strain of			Strain of		
Fabric code	10%	15%	20%	10%	15%	20%
S1	2.60 N	3.66 N	4.53 N	2.31 N	3.35N	3.43 N
R1	5.11 N	7.81 N	10.60 N	1.02 N	1.49N	1.89 N
T1	3.71 N	4.80 N	5.72 N	3.36 N	4.94 N	6.41 N

Figure 2, Figure 3, and Figure 4 show the elastic behaviour of different fabrics in different directions at 10%, 15%, and 20% strain. Overall, elastic behaviour shows a similar trend by increasing the strain significantly increase the load. At 10% strain, the behaviour of extension and retraction both S1 and R1 shows a similar trend. However, T1 in wale direction have a smaller load-strain curve compared to T1 in the course direction. At 15% strain, the load-strain curve of R1 in wale direction is bigger than the load-strain curve of R1 in course direction. While the load-strain curve of T1 is smaller in wale direction compared to the load-strain curve of T1 in course direction. At 20% strain, the load-strain curve of R1 in wale direction is bigger than the load-strain curve R1 in the course direction. At the same time, the load-strain curve of T1 is smaller in wale direction compared to the load-strain curve of T1 in course direction. Overall, the load-strain curve indicated that the recovery after an extension of the fabrics is significantly different between wale and course direction.



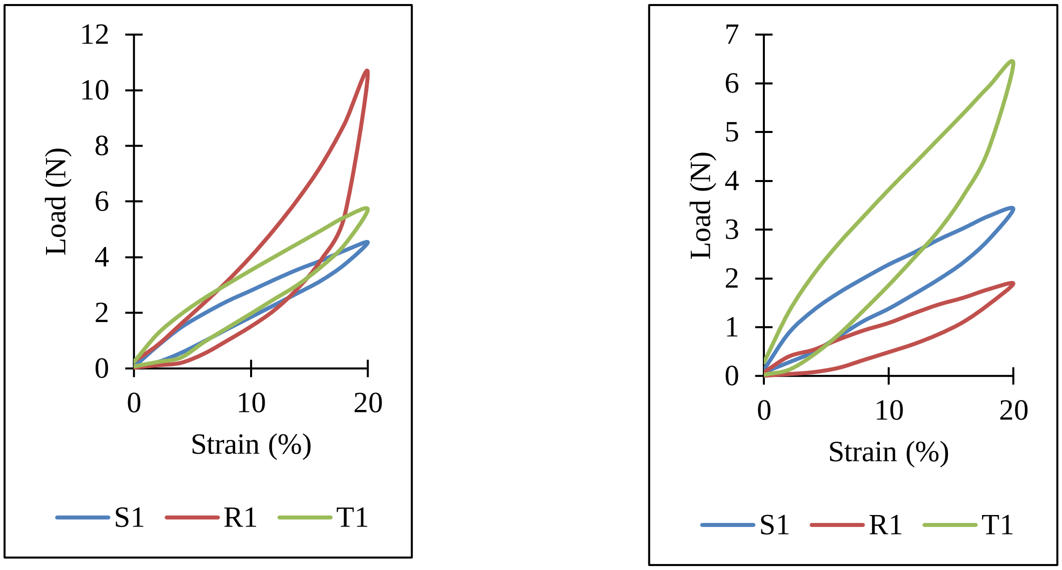
(a) (b)

FIGURE 1. Elastic behaviour of S1, R1 and T1 in a) wale direction b) course directions at 10% strain.



(a) (b)

FIGURE 2. Elastic behaviour of S1, R1 and T1 in a) wale direction b) course direction at 15% strain.



(a) (b)

FIGURE 3. Elastic behaviour of S1, R1 and T1 in a) wale direction b) course direction at 20% strain.

Analysis of variance (Table 3) reported that all mean values for each group are significantly different (P-value<0.05). A big value of F with a small P-value (less than 0.05) means that the null hypothesis is discredited. Null hypothesis here is that the group means are equal. It is proven that each variable gives a significant effect towards elastic performance of the fabrics. The interaction of fabric construction and fabric direction, fabric construction and strain level, fabric direction and strain level, and fabric construction, fabric direction, and strain level also have a significant impact on the load ($p<0.05$) to extend the fabric.

TABLE 3. ANOVA for maximum load of fabrics.

Source	DF	Sum of square	Mean square	F-Value	P-Value
Fabric construction	2	22.221	11.1103	83.64	0.000
Fabric direction	1	65.204	65.2037	490.83	0.000
Strain level	2	42.677	21.3387	160.63	0.000
Fabric construction*Fabric direction	2	104.852	52.4262	394.65	0.000
Fabric construction*Strain level	4	1.890	0.4725	3.56	0.015
Fabric direction*Strain level	2	2.572	1.2861	9.68	0.000
Fabric construction*Fabric direction*Strain level	4	6.778	1.6946	12.76	0.000
Error	36	4.782	0.1328		
Total	53	250.977			

In considering the effectiveness of the compression garment over the course of treatment, the extent of fabric tension deformation after repeated extension was examined. The fabric specimens were extended at 10%, 15% and 20% by using a tensile machine for 5 cycle extension cycles and the percentages of fabric tension decay obtained are presented in Table 4. All the three fabric samples exhibit a certain amount of tension loss after extension cycles. Amongst the three fabrics, fabric R1 has higher percentages of tension reduction in wales direction after repeated extension. Fabric R1 is relatively stable in course direction, only decaying about 1.45% to 2.87%. However, the fabric is considerably decayed in wale direction especially in 20% strain, which is 3.64% of tension decay. This may explain the highest load compared to other fabrics. According to [18], fabrics with high load tend to have major tension decay upon repeated strain and use. This leads to large amounts of fabric pressure change after repeated use of the compression garment. Fabric R1 is also relatively light fabric weight (263.76g/m^2) compared to S1 and T1. Fabrics T1 is relatively heavy in weight (345.58g/m^2), which has less effect on tension deformation upon repeated extension. Some associations may exist between fabric weight and tension decay behaviour [18]. The single jersey construction of fabric S1 is relatively stable, particularly in the wales and course direction. The tension decay only 1.25% to 2.97% in wale direction and 1.41% to 2.95% in course direction. The result indicates that fabric S1 has a similar trend of fabric decay in both directions.

TABLE 4. Fabric tension decay after 5 cycles of extension.

	Wale direction			Course direction		
	Strain of			Strain of		
Fabric code	10%	15%	20%	10%	15%	20%
S1	1.25%	2.24%	2.97%	1.41%	2.04%	2.95%
R1	2.58%	2.64%	3.64%	1.45%	2.71%	2.87%
T1	1.17%	1.23%	1.97%	1.24%	1.58%	1.87%

Analysis of variance (Table 5) reported that all mean values for each group is significantly different (P-value<0.05). It is proven that each variable gives significant effect towards tension decay of the fabrics. The interaction of fabric construction and fabric direction, fabric construction and strain percentages, fabric direction and strain percentages, and fabric construction, fabric direction, and strain percentages also have a significant impact on the tension decay of the fabric (p<0.05).

TABLE 5. ANOVA for tension decay of fabrics.

Source	DF	Sum of square	Mean square	F-Value	P-Value
Fabric construction	2	16.008	8.00392	115.04	0.000
Fabric direction	1	1.039	1.03889	14.93	0.000
Strain level	2	6.385	3.19267	45.89	0.000
Fabric construction*Fabric direction	2	2.573	1.28650	18.49	0.000
Fabric construction*Strain level	4	8.472	2.11797	30.44	0.000
Fabric direction*Strain level	2	4.870	2.43481	34.99	0.000
Fabric construction*Fabric direction*Strain level	4	1.311	0.32769	4.71	0.004
Error	36	2.505	0.06958		
Total	53				

CONCLUSIONS

In this study, three different knitted fabric constructions were selected to determine the impact of fabric construction on elastic behaviour and tension decay of compression garments. 1x1 rib recorded the highest load needed to extend the fabric in wales direction compared to single jersey and terry fabric. While in course direction terry recorded the highest load needed to extend the fabric compared to single jersey and rib fabric. It was found that fabric construction and fabric strain of single jersey, 1x1 rib and terry knitted fabric had a significant impact on the load needed to extend. Thus, the selection of fabric direction to be extended also plays an important role in the development of compression garments. From the elastic behaviour of the fabrics, the pressure delivered by the fabrics also can be calculated when developing the compression garment. So, the suitable amount of pressure delivered to the skin can be chosen among the different construction of the fabrics. Next, all the fabrics exhibit a certain amount of tension loss after extension cycles. The fabric construction, fabric direction and strain level had a significant impact on the fabric tension decay.

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