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Assessment of seam tensile behaviour in weft knitted fabric after cyclic loading-the influence of fabric loop length

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This study investigates the tensile behaviour of seams in knitted fabrics under cyclic tensile loading to simulate everyday wear conditions. Single jersey polyester fabrics with varying loop lengths were sewn using two common stitch types (504 and 514) and subjected to cyclic loading up to 200 cycles. The effects of stitch type, fabric loop length, and cyclic loading on the tensile properties of the seams were evaluated. The results revealed that the breaking stress and strain of the sewn fabric were lower than those of the unsewn fabric, owing to the loss of fabric integrity. In contrast, cyclic loading significantly reduced the seam breaking strain and increased the tensile modulus, indicating reduced seam extensibility. Moreover, fabrics with longer loop lengths exhibited reduced extensibility and poorer fatigue recovery. These findings indicate that fabrics with shorter loop lengths exhibited higher breaking strain and lower tensile modulus. It was also suggested that stitch type 504, especially in small stress, is more suitable, particularly for fabrics with greater extensibility.

Keywords: Biomechanical loads, Seam tensile behaviour, Cyclic loads, Garment comfort, Loop length

1. Introduction

Humans engage in both routine and specialised physical activities, such as exercise and sports, which continuously subject clothing to mechanical stress. Over time, this repeated loading compromises garment performance and comfort. Seams, which join fabric panels through stitching, experience the highest strain levels. Due to the interlocking structure of sewing threads, stitch loops are particularly prone to damage and deformation under cyclic stress. Therefore, the impact of repeated stress on fabrics and seams must be closely examined to assess garment durability under these conditions. While extensive research has explored the fatigue behaviour of yarns[1,2], knitted fabrics[3,6,] woven fabrics[7,8,] composites[9-11] and specialised textile applications[12,13,] relatively few studies have focused on the fatigue performance and predictive modelling of seams in textile products.

In fatigue behaviour, repeated elongation can lead to permanent deformation, which is influenced by both the relaxation time and the number of loading cycles. This deformation is primarily due to plastic changes from fibre slippage and/or permanent fibre extension. Notably, the loop dimensions, such as the width and length, can affect the test outcomes[3] While an increased number of tensile cycles reduces sample elongation, fluctuating loads accelerate fabric deterioration and damage[4]. Fatigue performance is further influenced by the level of applied strain and the structural characteristics of the fabric. Lower strain levels generally result in better recovery and greater stability under repeated tensile fatigue due to the small deformation made in fabric[7]. Additionally, weave structure plays a significant role: firmer patterns like plain weaves, with more interlacing points and fewer floating yarns, exhibit higher elasticity compared to twill and satin weaves8. The assessment of the elastic recovery behavior of ISO-301 stitched seams demonstrated that the energy required for the initial extension was much greater than that for subsequent cycles due to the viscoelastic and time-dependent behavior of textile materials[14,15]. Besides cyclic tensile loading, bagging cyclic forces applied on the seam have a similar effect and can lead to decreased seam elongation and weaken the sewing thread[16]. Sajjadi et al. used finite element simulation to predict the mechanical behavior of sportswear seams under periodic load[17,18].

Seam fatigue is a critical factor that can negatively impact both the performance and appearance of garments, often resulting in issues such as seam grinning under cyclic tensile loading. Despite its

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importance, this area has received limited research attention. The aim of this study is to examine changes in the tensile behavior of knitted fabric seams under varying cyclic loading conditions. For this purpose, four weft-knitted fabrics with identical knit structures but different loop lengths were selected. Seamed samples were prepared using 504 and 514 stitch types, and the tensile properties of both the unseamed and seamed fabrics were measured up to the breaking point. Subsequently, the samples were subjected to different numbers of tensile loading cycles to simulate real wear conditions. Finally, the changes in the tensile behavior after cyclic loading were analyzed to assess the seam performance under fatigue.

2. Experimental

2.1. Materials

In order to investigate the effect of cyclic tensile loading on the seam strength of weft knitted fabrics with various loop lengths, single jersey fabrics with various loop lengths, including 1.75, 1.89, 2.14 and 2.2 mm, were knitted on a circular knitting machine with a gauge of 26 needles per inch. The fabrics were knitted from polyester spun yarn with a count of 30 Ne and a polyester filament yarn with a count of 150 Den. The characteristics of these fabrics are listed in Table 1.

2.2. Sample preparation

To evaluate the influence of repeated tensile loading on the tensile behavior of seamed fabric, the seamed fabrics should be subjected to cyclic tensile loading to simulate the wear condition of the garment. To this end, fabric samples were cut with dimensions of 35× 10 cm^2 with the longer edge along the course direction, because in a knitted garment, the seams are formed along the wale direction. Then, both ends of the sample were joined to each other to form a loop. To sew the samples, two stitch types, 504 and 514 (Figure 1), were used, which are common stitch types for sewing knitted fabrics. All samples were prepared with a seam type of SSa-1(This type of seam shall be formed by superimposing two or more plies of material and seaming them with one or more rows of stitches a specified distance from their edges.), seam allowance of 2 cm, and stitch length of 2.5 mm. To prepare the seamed samples, a polyester spun sewing thread with a count of 40/2 Nm was used as the needle thread and a polyester filament sewing thread with a count of 150 Den was used as the looper threads.

Table 1 — The characteristics of tested fabrics

Fabric ID	Thickness (mm)	Weight (g/m^2)	WPC (cm^{-1})	CPC (cm^{-1})	Stitch density (cm^{-2})	Loop Length (mm)
F1	0.72	182	13	22	286	1.75
F2	0.68	165	12	20	240	1.89
F3	0.67	154	11	18	198	2.14
F4	0.66	143	10.5	17	178.5	2.2

2.3. Test method

2.3.1 Cyclic loading of seamed fabrics

To simulate the wearing conditions of the garment, a MICRO350 tensile testing machine was used, as shown in Figure 2. The distance between the two jaws was 100 mm, and the extension rate was 1000 mm/min. The number of cyclic loadings of the seamed samples was 50, 100, 150, and 200 cycles to investigate the impact of the number of cyclic loadings on the tensile behavior of the seamed fabric. During the cyclic loading process, the upper jaw moved upward and downward continuously until the desired number of cycles was completed. The value of the applied strain for the samples was determined based on their tensile behavior around the yield point. In this regard, a tensile load was applied perpendicularly to the seam line to simulate the wear condition.

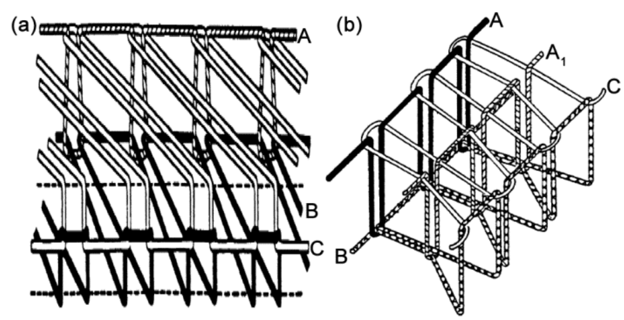

Fig. 1 — Diagram of, (A) stitch type 504, (B) stitch type 514[19].

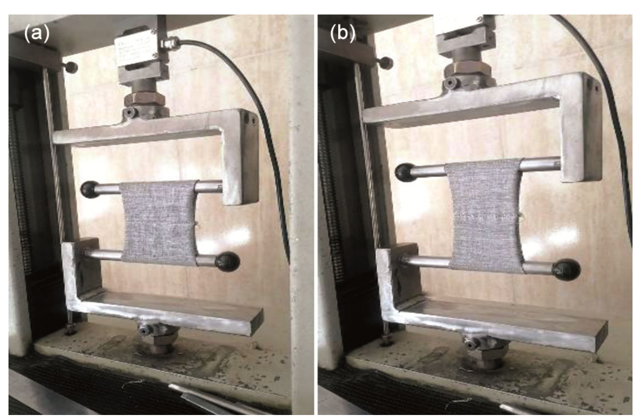

Fig. 2 — Cyclic loading of the seamed samples. A. The lower position of the jaw. B.The upper position of the jaw

2.3.2 Tensile behavior of seam

The tensile behavior of the seamed fabrics was measured using a MICRO350 tensile testing device according to the ASTM D1683 standard test method. As mentioned previously, the seam strengths of the seamed samples were measured before and after cyclic loading with 50, 100, 150, and 200 tensile loading cycles. To measure the seam strength of the samples, the gauge length was set to 100 mm, and the test was performed at an extension rate of 50 mm/min. As shown in Figure 3, the test was continued until the seam ruptured.

Fig. 3 — Measuring seam strength of samples

3 Results and discussion

3.3 Tensile behavior of fabrics with seam and without seam

The tensile behaviors of fabrics knitted with various loop lengths before and after sewing with 504 and 514 stitches were measured until the breaking point, and the stress-strain diagram of the samples is illustrated in Figure 4.

According to Figure 4, the trend of stress variation in terms of strain for all fabric samples before and after sewing is similar. In other words, before the yield point, the slope of the diagram is lower; however, after the yield point, the slope of the diagram increases. The first section of the stress-strain curve is related to the deformation of fabric loops in the knitted fabric, and because of the high extensibility of the fabric in this zone, applying low stress leads to a large strain in the fabrics. Conversely, after the yield point due to the extension of loops and yarn, a higher stress is needed to extend the fabric, and this section eventually leads to sample failure. Although the general trends of the stress-strain diagrams for fabrics with and without seams are the same, the breaking stress and strain differ. To evaluate the tensile performance of the fabrics before and after sewing, parameters that present the tensile properties of samples, such as breaking stress, breaking strain, and tensile modulus, should be considered. The tensile behaviors of the fabrics with and without seams are summarized in Table 2. The tensile behaviors of various fabrics before and after sewing are compared in Figure 5.

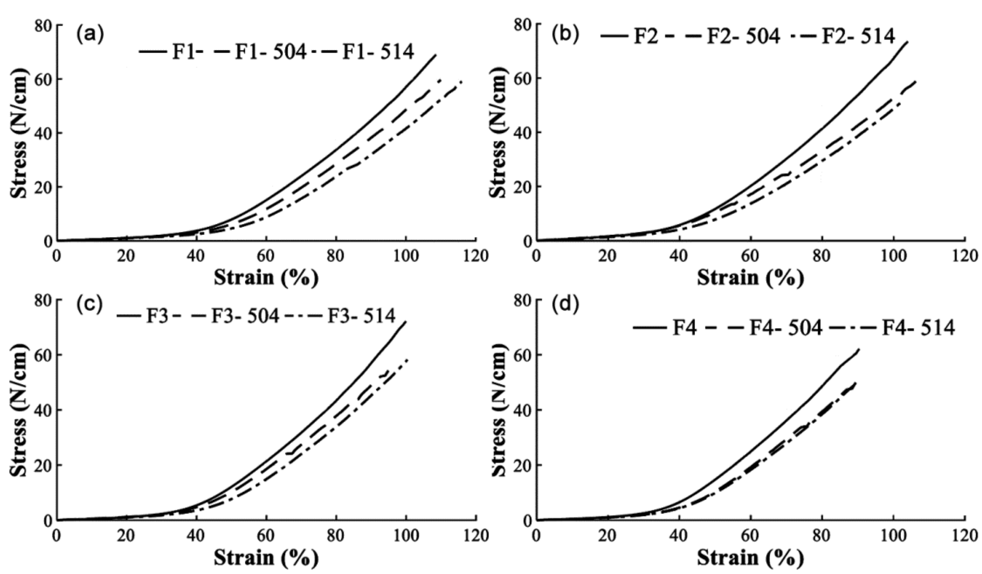

Fig. 4 — Tensile behavior of seamless and sewn samples before cyclic loading

Table 2 — Tensile behavior of fabric with and without seams.

Fabric ID	Stitch type	Tensile modulus (N/cm)		Breaking stress (N/cm)		Breaking strain (%)	
		Mean	S.D	Mean	S.D	Mean	S.D
F1	Seamless	0.092	0.008	68.94	2.12	108.6	**1.47**
	504	0.078	0.010	59.56	1.52	109.9	2.81
	514	0.063	0.008	59.04	1.51	116.98	3.12
F2	Seamless	0.144	0.010	73.42	2.30	104	1.50
	504	0.138	0.020	61.12	1.18	108.3	2.09
	514	0.103	0.015	50.77	0.98	101.8	1.96
F3	Seamless	0.136	0.009	72.10	2.53	99.9	1.32
	504	0.119	0.022	54.19	1.31	94.9	2.29
	514	0.089	0.016	58.15	1.41	100.3	3.00
F4	Seamless	0.164	0.011	62.06	2.08	90.4	1.22
	504	0.104	0.008	55.54	1.11	98.49	3.06
	514	0.109	0.008	50.32	1.01	89.8	1.79

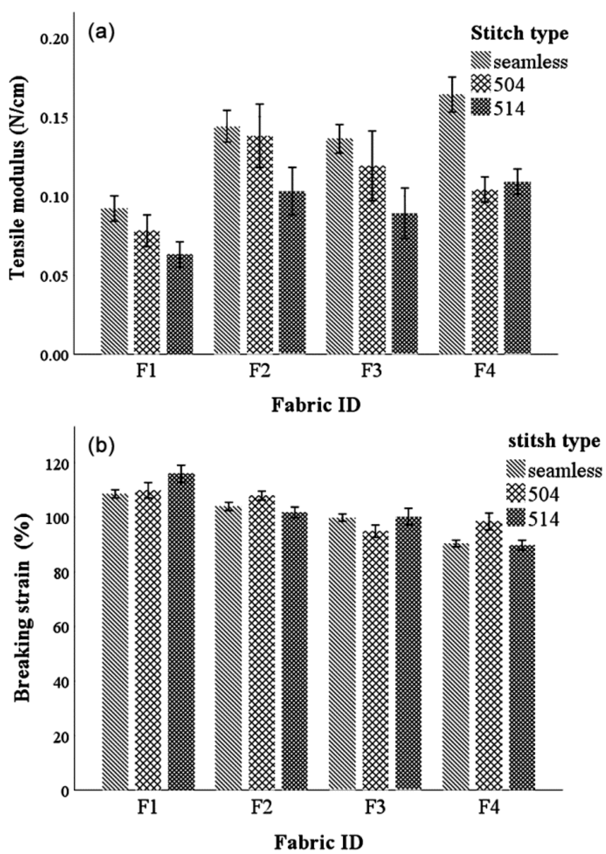

Fig. 5 — Tensile behaviors of various fabrics before and after sewing

As shown in Figure 5, the breaking stress of all samples decreased after sewing, regardless of the stitch type. This reduction was attributed to the loss of fabric integrity resulting from the introduction of seams. In other words, seamless fabrics consistently exhibit higher strengths than seamed fabrics. In addition, variations in the loop length affect the tensile behavior of the fabric before and after sewing. Specifically, an increase in loop length decreased the breaking strain. This is because longer loop lengths reduce the loop density of the fabric, thereby reducing its extensibility. Accordingly, samples F1 and F4 exhibited the highest and lowest breaking strains, respectively. However, no significant differences were observed between the two stitch types in terms of seam strength and extensibility, but was observed in terms of tensile modulus.

The results of the statistical analysis performed using the ANOVA test showed that the influence of the loop length of knitted fabric on the breaking strain of fabrics and seams at the confidence level of 95% (p-value <0.05) is significant. Moreover, the impact of sewing on the breaking stress of fabrics and seams at a confidence level of 95% (p-value=<0.05) is meaningful.

3.2 The effect of cyclic loading on the seam tensile behavior

As mentioned previously, this study aimed to assess the influence of cyclic tensile loading on the seam tensile behaviors of knitted fabrics. Therefore, the seam strength of the samples was measured after 50, 100, 150, and 200 cycles of tensile loading. Since the applied tensile load needed to remain below the breaking stress and close to the yield point, a strain level of 40% was selected for all samples based on their respective stress–strain diagrams. A typical stress–strain diagram of sample F1, sewn with stitch type 514 and subjected to 200 loading cycles, is presented in Figure 6. Following cyclic loading, the tensile behavior of the seamed samples was evaluated until the seam ruptured.

In Tables 3 and 4, the tensile behaviors of the samples sewn with 504 and 514 after various cyclic loadings are calculated. Based on the results, it is evident that cyclic tensile loading prior to seam strength testing leads to a reduction in both seam breaking stress and strain for all samples. Although a noticeable decrease in the breaking strain was observed after cyclic loading, the high extensibility of the tested knitted fabrics appeared to mitigate the impact on the seam breaking stress. As a result, the influence of cyclic loading on seam strength was less pronounced compared to its effect on strain. Furthermore, an increase in the number of applied cyclic loadings led to a greater reduction in the seam

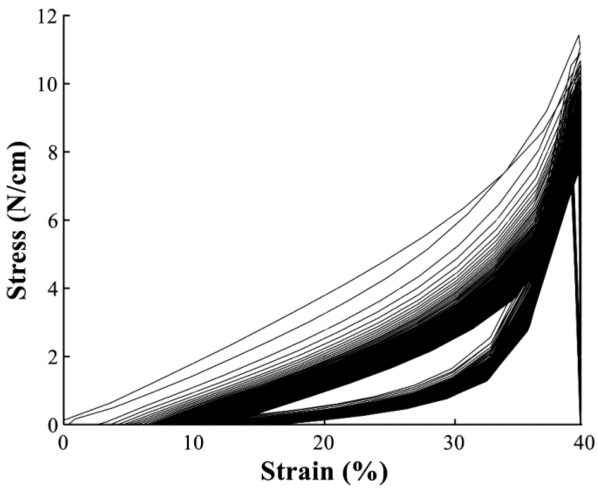

Fig. 6 — A typical stress-strain diagram of 200 cyclic loading of sample F1- 514- 200

breaking strain, such that the seamed fabric that tolerated 200 cyclic loadings presented the lowest seam strain.

Under identical loading conditions and cycle counts, fabrics with shorter loop lengths and higher loop densities exhibited higher breaking strain and lower tensile modulus. This suggests that fabrics with greater extensibility possess better recovery characteristics and greater resistance to repeated tensile fatigue. In contrast, fabrics with higher loop lengths and lower loop density exhibit poorer recovery, which can be attributed to factors such as intrinsic hysteresis loss, energy dissipation due to fibre-to-fibre friction, and progressive loosening of the fabric structure, ultimately leading to fibre breakage.

In order to assess the garment performance under repeated use in small stress, the variation of tensile modulus of samples in terms of number of cyclic loadings for both 504 and 514 stitch types are investigated. An increase in the number of loading cycles led to a increment in the tensile modulus of the seamed samples for both stitch types, a trend consistently observed across all tested fabrics. This reflects a decrease in the sample extensibility with increasing cyclic loading. Repeated loading and extension induce permanent deformation, primarily due to fiber slippage and/or permanent fiber

Table 3 — Tensile behavior of fabric with 504.

Fabric ID	Number of loading cycles	Tensile modulus (N/cm)		Breaking stress (N/cm)		Breaking stress (N/cm)	
		Mean	S.D	Mean	S.D	Mean	S.D
F1	0	0.078	0.010	59.56	1.52	109.9	2.81
	50	0.086	0.025	60.54	1.98	106.60	3.49
	100	0.109	0.012	58.33	2.02	100.44	3.47
	150	0.097	0.008	52.05	1.75	94.58	2.81
	200	0.095	0.010	29.39	1.94	76.88	5.07
F2	0	0.138	0.020	61.12	1.18	108.3	2.09
	50	0.139	0.014	62.35	0.84	104.71	1.41
	100	0.116	0.014	60.75	0.95	104.75	1.64
	150	0.148	0.017	62.01	0.95	100.76	1.54
	200	0.203	0.012	61.23	1.16	96.77	1.79
F3	0	0.119	0.022	54.19	1.31	94.9	2.29
	50	0.140	0.012	55.95	0.65	89.94	1.04
	100	0.184	0.020	50.60	1.33	82.75	2.18
	150	0.212	0.019	35.07	0.96	65.84	1.81
	200	0.238	0.005	33.77	1.68	63.88	3.18
F4	0	0.104	0.008	55.54	1.11	98.49	1.96
	50	0.089	0.014	61.56	1.26	100.91	2.06
	100	0.153	0.013	59.46	0.69	90.96	1.06
	150	0.341	0.011	62.60	1.07	77.98	1.33
	200	0.402	0.019	55.01	1.64	69.96	2.08

Table 4 — Tensile behavior of fabric with 514.

Fabric ID	Number of loading cycles	Tensile modulus (n/cm)		Breaking stress (n/cm)		Breaking strain (%)	
		Mean	S.D	Mean	S.D	Mean	S.D
F1	0	0.063	0.008	59.04	1.51	115.98	2.97
	50	0.100	0.029	52.02	1.70	99.79	3.27
	100	0.132	0.015	59.28	2.05	98.03	3.39
	150	0.153	0.013	58.33	1.56	93.56	2.51
	200	0.191	0.020	57.35	3.79	86.99	5.74
F2	0	0.078	0.015	59.56	0.98	109.97	1.96
	50	0.114	0.011	61.82	0.83	100.96	1.36
	100	0.175	0.021	61.28	0.95	90.94	1.42
	150	0.170	0.020	65.39	1.00	91.24	1.39
	200	0.273	0.016	61.33	1.08	80.88	1.44
F3	0	0.089	0.016	58.15	1.41	100.3	2.42
	50	0.130	0.011	58.64	0.68	97.45	1.13
	100	0.169	0.018	58.69	1.54	90.07	2.37
	150	0.207	0.019	52.41	1.43	80.53	2.21
	200	0.230	0.005	56.34	2.98	78.76	4.03
F4	0	0.109	0.008	50.32	1.01	89.8	1.79
	50	0.130	0.020	51.78	1.06	87.90	1.79
	100	0.237	0.020	55.23	0.64	79.88	0.93
	150	0.325	0.010	59.97	1.02	77.64	1.32
	200	0.495	0.023	59.12	1.93	68.43	2.13

elongation. Moreover, cyclic extension contributes to material fatigue, thereby increasing plasticity over time. As plastic deformation accumulated with more loading cycles, the tensile modulus increased. Also, the results show that with increasing cyclic loading, the increment in the tensile modulus and plastic deformation in the samples sewn with stitch type 514 were more than sewn with stitch type 504 . Therefore, it is suggested that the stitch type 504 is used especially for fabric with greater extensibility.

4 Conclusion

The tensile behavior of knitted fabric seams is significantly influenced by the stitch type, fabric loop length, and cyclic loading. Sewing reduces the fabric breaking strength due to structural discontinuity at the seam, and repeated cyclic loading decreases seam extensibility by inducing plastic deformation and fiber slippage in the sewing threads. Additionally, fabrics with a higher loop density (shorter loop length) exhibited better tensile recovery and resistance to cyclic fatigue. The stitch type with lower contact area with fabric and higher extesibility improve the garment performance under repeated use in small stress. Understanding these relationships is crucial for optimizing seam design and fabric selection to enhance the durability and comfort of casual and sportswear subjected to repetitive mechanical stresses.

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