Explanation of Warp Knitted Fatigue Behavior under the Cyclic Extension by using Holloman's Relation

Mir Reza Taheri Otaghsara[i] ; Ali A.A. Jeddi[ii] ; Jamshid Aghazedeh Mohandesi[iii]

ABSTRACT

In this study, tensile and fatigue behavior of seven different structure (Tricot, Locknit, reverse Locknit, three needle Satin, four needle Satin, three needle Sharkskin and four needle Sharkskin) of warp knitted fabrics with three different course density (cpc) have been studied. The correlation between tensile and [iv]fatigue behavior of these fabrics with structural parameters have been investigated. The space of yarn movement and the length of underlaps are taken into consideration as basic parameters influencing the corresponding mechanical behavior. The obtained results show that with the increase in underlap length and/or cpc, the breaking extension percent is decreased while the breaking tenacity is increased. Cyclic extension causes stress relaxation and strain softening in the warp knitted fabrics. Application of Holloman's relation (σ=K ε^n) to the results of tensile and fatigue tests shows that strength coefficient (K) is decreased by fatigue process, while strain-hardening coefficient (n) is increased. By increasing underlap length, the cyclic stabilized load and strain-hardening coefficient is increased. Also, the cyclic stabilized load and the strain-hardening coefficient in fabrics with longer back guide bar underlap is higher than those with the same length in front guide bar.

KEYWORDS

Fabric fatigue, Warp kitted fabrics, Tensile property, Fatigue property, Cyclic extension, Strain hardening, Holloman's relation

1. INTRODUCTION

Fatigue of textile materials has been investigated by many researchers [1-8]. Prevorsek and Lyons [1,2] have studied the fatigue behavior of textile fibers. In these studies, fatigue life under constant total extension (stroke), rather than stress amplitude has been taken as a more practical method for the case of single fiber specimens. In a general introduction to a series of investigation [3], a brief consideration was given to the distribution of individual lifetime of an acrylic sample at a given frequency and stroke. Lyons [4] have studied the effect of frequency of cyclic loading on fatigue endurance of acrylic fibers and presented the equation N= a v^{-n} where N is the number of cycle that fibers withstand under cyclic loading, v is the frequency, a is a function of stroke, and n is a constant>0. Lyons [9-13] and Lyons and Ribnik [14] have shown that the stroke and frequency of cyclic loading, temperature, molecule structure and molecule weight of fibers effect on the fatigue behavior of fibers. They observed stress decrement and non-recoverable extension during each cycle

which are functions of stress relaxation and creep extension. Narisava et al. [15] investigated the fatigue behavior of nylons at fixed extension strokes and the growth

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of specimen was not taken up. They bserved that stress amplitude gradually decreased to a stationary value with increasing number of fatigue cycles.

Frank and Singleton [6] showed that plasticizers in the form of heat and/or water tend to increase the fatigue life of filament yarns. They observed that durability of nylon, polyester and viscoseryon yarns against cyclic deformation depending on the frequency of cyclic straining, temperature, humidity of ambient differed each other and depend on the structure and physical properties (regain and thermoplastic property) of these yarns. Jeddi et al. [7] have investigated the tensile fatigue behavior of cotton-polyester blended spun yarns. They concluded that yarn decrimping, fiber slippage and fiber elongation are the factors that influence fatigue endurance of the yarn, and the polyester component in the blended yarn causes significant improvement of damping ability and the fatiguing resistance of the yarn under the tensile cyclic loading.

Few papers have concentrated on the fatigue behavior of textile fabrics. Kobliakov et al. [8] reported limited experimental results on tensile fatigue behavior of woven and knitted fabrics under different frequencies of cyclic straining and stroke. They found that by increasing the frequency of cyclic loading the fabrics deformation (i.e., the ratio of non-recoverable elongation to the initial length of specimen) decreases, however with the increase in the stroke, the deformation increases, they also showed that this deformation for knitted fabrics is higher than woven fabrics, and weft knitted fabrics reach the final deformation limit earlier than the woven fabrics. Jeddi et al. [16] have designed a machine for fatiguing the warp knitted fabrics. They knitted fabrics (i.e., Tricot, Locknit, Reverse Locknit, Satin and Sharkskin) and investigated the relationship between fatigue behavior of fabrics and their structural parameters. They observed that the phenomenon of fabrics fatigue under cyclic tension depend on the geometry of fabric structure, and the final deformation and tensile modulus of the fabrics increased as the number of fatigue cycles increased, while tensile breaking extension% decreased. Ben Abdessalem et al. [17] have developed a new experimental device permitting to test dimensional behaviors of knitted fabrics under large number of cyclic elongation. They observed that the fatigue test applied to a plain knitted fabric made of cotton involved a variation fabrics dimensions and a permanent deformation that persists after relaxation and this permanent deformation depends widely on the number of repetitive cycles. Also, they concluded that the deformation involved by fatigue test corresponds to a displacement and a lengthening of the yarn composing the loop.

In the present study, two fully threaded guide bars warp knitted fabrics were produced from polyester textured filament yarn count 11.2 tex (100 denier). The objects of this investigation are the study of tensile behavior of these fabrics and the effects of fabric structures, course density (cpc) and amplitude of cyclic extension on their fatigue behavior and to obtain the cyclic stabilized load of fabrics in different amplitude of extension. Then, we use Holloman's relation to obtain the strain-hardening coefficient and strength coefficient to asses the behavior of fabrics after fatiguing.

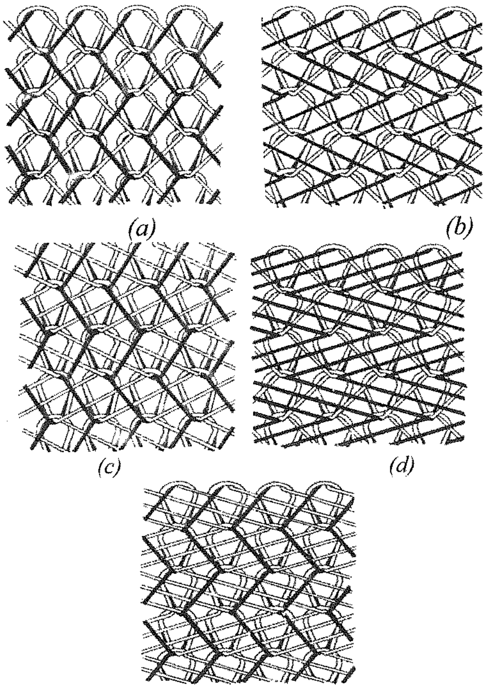

Figure 1: Double guide bar warp knitted fabrics.(a) Tricot; (b) Locknit; (c) Reverse Locknit; (d) Three needle Satin; (e) Three needle Sharkskin.

2. MATERIAL AND METHODS

The fabric samples were made on a Karl Mayer Ketten KH_2 machine, with gauge 28 (28 needle per inch). These fabrics are Tricot, Locknit, Reverse Locknit, three needle Satin, four needle Satin, three needle Sharkskin and four needle Sharkskin, and each of them knitted in three different course density setting (15, 20, and 25 cpc). Figure 1 shows five fabric structures. After knitting process, all the fabrics were washed to remove spin finish and industrial oil contaminants and then heat set. After heat setting the cpc of fabrics were slightly changed. The characteristics of fabrics are shown in Table 1.

A. Tensile Tests

To study the tensile properties of the fabrics and in order to obtain the parameters of cyclic tests, fabric samples were tested on a servo-hydraulic **Instron 8502** testing machine. Considering high load capacity (±500kN) of the testing machine, in order to increase the accuracy of measurements, the specimens of 50cm width were 8 folded for tensile tests. Five specimens with 50mm gauge length for each fabric were tested in course direction. The reason for choosing 50 mm gauge length is the limitation of the movement course of the moving clamp. Two typical load-extension diagrams (T_2 and SHF_3) are demonstrated in Figure 2.

TABLE 1
CHARACTERISTICS OF KNITTED FABRICS.

Fabric Structure (No. of underlap) FB* BB*	Fabric code	Run-in (cm) FB	Run-in (cm) BB	Fabric density (cm^{-1}) cpc*	Fabric density (cm^{-1}) wpc*
Tricot 1 1	T_1	163.3	153	20.2	12.1
	T_2	142.7	138.7	23	13.5
	T_3	135.7	127	25.2	14.7
Locknit 2 1	L_1	208	156.4	18	14.8
	L_2	190	135	21.1	15.9
	L_3	176.7	126	23.1	16.8
Reverse Locknit 1 2	RL_1	168.5	196	18.1	13.1
	RL_2	153	177.5	21.7	13.8
	RL_3	143.4	168.7	25.2	13.7
Satin 3 3 1	ST_1	250.5	155	16.8	15.8
	ST_2	231	127	20.5	16.5
	ST_3	216	121.5	22.7	16.8
Satin 4 4 1	SF_1	289	155	16.4	16.2
	SF_2	271.5	129	20.5	16.9
	SF_3	259.4	22.4	23	16.8
Sharkskin 3 1 3	SHT_1	171.5	234.5	17.5	13.1
	SHT_2	153	221.5	21.7	13.7
	SHT_3	150	207.1	23.5	13.7
Sharkskin4 1 4	SHF_1	170.5	279	17.7	13
	SHF_2	148	274.5	21.3	2.6
	SHF_3	148	267.5	22.6	12.5

FB: front guide bar; BB: back guide bar; cpc: course per cm; wpc: wale per cm.

As shown in Figure 2, the diagram of load-extension of all fabrics has two slopes, and then the specimen will break. The angle of second slope is wider and slopes are separated by a knee which is taken into consideration as a criterion for obtaining the amplitude of cyclic extension in fatigue test.

B. Fatigue Tests

After cycling a material for a relatively short duration, the hysteresis loops generally stabilizes and the material achieves equilibrium condition for imposed strain limits.

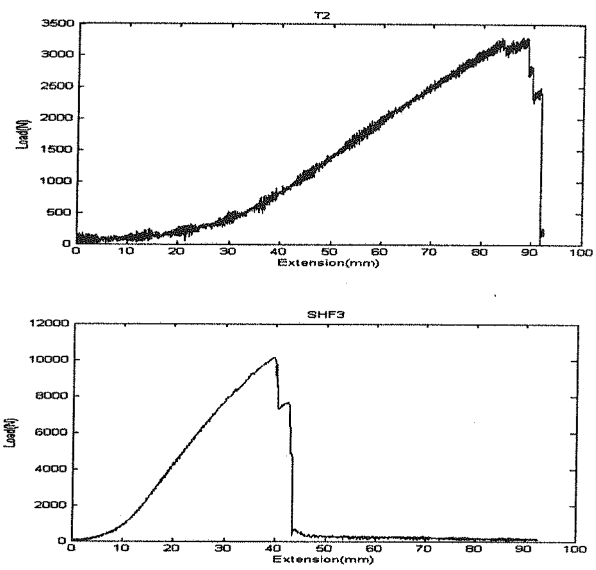

Figure 2: Typical load – extension diagrams of T2 and SHF3 samples.

The cyclic stress-strain response of the material may then be quite different from the initial monotonic response. Cyclically stress-strain curves are important characterizations of a material's cyclic response. These curves may be obtained in several methods [18]: **1.** A series of companion samples may be cycled within various strain limits until the respective hysteresis loops become stabilized. The cyclic stress-strain curve is then determined by fitting a curve through the tips of the various superimposed hysteresis loop. **2.** A faster method for obtaining cyclic stress-strain curves is by multiple step testing, wherein the same sample is subjected to a series of alternating strains of increasing magnitude. In this manner, one specimen yields several hysteresis loops, which may be used to construct the stress-strain curve. **3.** An even quicker technique involving only one sample has been found to provide excellent results and is used extensively in current cyclic strain testing experiments. In this manner, the specimen is subjected to a series of blocks of gradually increasing and then decreasing strain excursion. In the present study, the first method was used to achieve more accuracy in the tests.

The specimens for the purpose of fatigue tests were prepared as mentioned for tensile tests and all fatigue tests were carried out under a preload of 500 N. This preload causes an extension which is settled down in the second slope of load-extension diagram for all fabric samples. The amplitude of cycling were 2,4,6,8,10 and 12mm, were chosen from the elongation of fabrics in order to conduct cycling in the second slope region of load-extension diagram of fabrics samples. For each abovementioned amplitude of extension one sample has been tested.

In this study, the **FLAPS** software (Fatigue Life Analysis Programs) has been applied to run the tests and data acquisition. The frequency of cycling was set at 0.5 Hz, and data sampling rate was set at 2 Hz. Each sample has been tested during 500 cycles.

Load-strain curves have been used instead of stress-strain curve to assess the effects of fatigue loading on the fabrics. To obtain the cyclic load-strain curve, a computer program was written by using MATLAB software to obtain the cyclic stabilized load in each fatigue test. The maximum load for first cycle in each test has taken as monotonic load for given amplitude to draw the monotonic load-strain curves.

3. RESULTS AND DISCUSSIONS

The amplitude of slippage and movement of components of materials over each other owing to tension or compression are the important factors that influence the elastic behavior of materials. Therefore, when a filament yarn is subjected to a tensile load, its strain depends on the ability of the movement of molecule chain on each other. This phenomenon, in fabrics depends not only on the nature of the yarn used in fabric, but also on the structural properties of the fabric. It means that the strain and ability of fabrics to withstand against a given load depend on the slippage and movement of yarns in the fabric structure. In warp knitted fabrics, the following two structural parameters have significant role in fabric elasticity [16]:

1) The space for yarn movement; this space allows yarn movement over each other inside the fabric structure. In double guide bar warp knitted fabrics, this space is formed between overlaps and front guide bar underlap and the movement of back guide bar underlap depends on the extent of this space. If this space is large enough, the back guide bar underlap can move easily.

2) The length of underlaps; with increase in the length of front and/or back guide bar underlap length, then the strain value in the course direction will be decreased while in the wale direction it will increased.

The existing space for yarn movement plays the main role in elastic behavior of warp knitted fabric rather than the length of underlap. Very often these two parameters have an opposite influence on fabric elasticity.

A. Tensile Properties

The average results of tensile test of fabrics are shown in Table 2. Statistical examination at 95% confidence limit has applied to the tensile results. Table 3 shows the results of ANOVA test. This table shows that Duncan statistical test can be used for breaking extension and breaking tenacity grouping. Table 4 shows the grouping for breaking extension and breaking tenacity of studied fabric structures in different cpc levels. As shown in Table 4, the breaking extension and the breaking tenacity of all fabric structures with different cpc are settled nearly in three distinguished group except breaking extension of Locknit structure (L).

TABLE 2
THE AVERAGE RESULTS OF TENSILE TESTS.

Fabric code	Breaking Extension (mm)	Breaking Tenacity (N)
T_1	85.4	3072
T_2	83.59	3277
T_3	81.86	3509
L_1	73.75	3142
L_2	72.11	3344
L_3	71.54	3898
RL_1	75.16	3635
RL_2	65.66	4710
RL_3	56.79	5743
ST_1	59.5	3968
ST_2	57.2	4154
ST_3	55.3	4323
SF_1	57.3	5873
SF_2	54.51	6278
SF_3	51.47	6636
SHT_1	53.28	5340
SHT_2	46.8	7075
SHT_3	42.33	7767
SHF_1	46.1	7956
SHF_2	38.78	9643
SHF_3	37.24	10350

Figure 3 shows graphically the average breaking elongation results of the fabrics in tensile tests. The beaking elongation in fabrics with longer back guide bar underlap is lower than those with the same length of underlap in front guide bar (RL<L, SHF<SF and SHT<ST). This is because of the shorter length of front guide bar under lap than back guide bar underlap and then less accessible space for back guide bar underlap in fabrics RL, SHT, and SHF. This smaller space causes limited yarn movement in these fabrics. With the increase of cpc and number of underlap the breaking elongation is decreased. These phenomena are because of the

TABLE 3
ANOVA TEST ON THE TENSILE PROPERTIES AT 95% CONFIDENCE LIMIT.

	Breaking Extension		Breaking Tenacity	
Structure	F	Sig.	F	Sig.
T	7.214	0.009	19.37	0.000
L	1.802	0.207	36.01	0.000
RL	79.763	0.000	313.3	0.000
ST	5.690	0.018	6.126	0.015
SF	6.600	0.012	34.07	0.000
SHT	25.586	0.000	315.0	0.000
SHF	22.525	0.000	380.2	0.000

closer angle between underlaps and direction of tensile load in fabrics with higher course density (cpc) and/or more number of underlaps. For this reason, the yarn movement and thereafter the fabric elongation is limited.

TABLE 4
DUNCAN GROUPING ARRANGEMENT FOR BREAKING EXTENSION AND BREAKING TENACITY.

Structure	cpc	Breaking Extension Group			Breaking Tenacity Group		
		1	2	3	1	2	3
T	Level 1	85.4			3072		
	Level 2	83.6	83.6			3277	
	Level 3		82.0				3509
L	Level 1	71.5			3142		
	Level 2	72.1				3344	
	Level 3	73.8					3898
RL	Level 1	75.3			3635		
	Level 2		65.7			4710	
	Level 3			56.8			5743
ST	Level 1	59.5			3968		
	Level 2	57.2	57.2		4154	4154	
	Level 3		55.3			4323	
SF	Level 1	57.3			5873		
	Level 2	54.5	54.5			6278	
	Level 3		51.5				6638
SHT	Level 1	53.3			5340		
	Level 2		46.8			7075	
	Level 3			42.3			7767
SHF	Level 1	46.1			7956		
	Level 2		38.8			9643	
	Level 3		37.2				10350

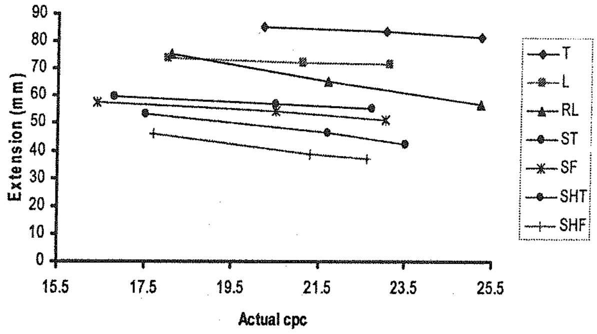

Figure 3: Breaking elongation of fabrics in different actual cpc.

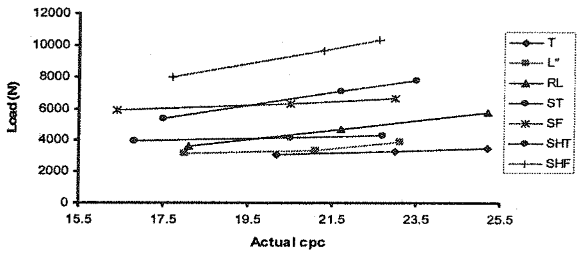

Figure 4: Breaking tenacity of fabrics in different actual cpc.

Figure 4 shows the breaking tenacity of fabrics. This figure shows that the breaking tenacity of fabrics with longer back guide bar underlap is higher than fabrics with the same length in front guide bar underlap. This phenomenon can be explained as existing of less space for the movement of back guide bar underlap in those fabrics. Also, Figure 4 shows that with the increase of cpc the breaking tenacity of fabrics is increased. The main reason of this result is the existence of more courses in the samples of higher cpc.

B. Fatigue Properties

Figure 5 shows typical diagram of load-extension and load-time for T_1 and SHF_2 samples in cyclic test. As illustrated in this figure, the maximum load gradually decreases in subsequent cycles and there is a hysteresis loop that the width of this loop also decreases gradually. The trend of variation of maximum load shows that this load will reach to a constant amount as cyclically stabilized load and fabric samples achieve the equilibrium condition for the corresponding imposed strain. The main parameters of cyclic tests and maximum load at first cycle and stabilized state of fabrics are tabulated in Table 5.

The maximum load in first cycle and the maximum load in stabilized state have registered for comparing behaviors of fabrics before and after fatigue process (Table 5). Figure 6 shows typical regression diagram of monotonic and cyclically stabilized load-strain curves for two fabric structures of Tricot and four needles Sharkskin with nominal cpc 15. By comparing the monotonic and cyclically stabilized load-strain curves (Figure 6), it can be seen that cyclic stabilized load-strain curve is placed under the monotonic load-strain curve. This indicates that, fatigue process causes strain softening in fabrics. These observation can be explained by stress relaxation of yarn in fabric structure [1,4,6,7,16] and the deformation of loop shape[17].

Figure 7 shows a typical cyclic stabilized load- amplitude regression curve for Locknit (L) and three needle Sharkskin (SHT) structures with different cpc. It can be seen that by increasing cpc, the cyclic stabilized load of fabrics is increased. The main reason for this phenomenon is the presence of more courses in specimen and the higher friction between yarns, in the structures with higher cpc.

The regression curve for cyclic stabilized load of all fabric structures with nominal cpc 20 in different amplitude of cycling is shown in Figure 8. This figure shows that by

TABLE 5

PARAMETERS OF TESTS AND MAXIMUM LOADS AT FIRST CYCLE AND AT STABILIZED STATE IN FATIGUE TESTS.

Sample code	PE (mm)	AC (mm)	ML (N)	SL (N)	Sample code	PE (mm)	AC (mm)	ML (N)	SL (N)	Sample code	PE (mm)	AC (mm)	ML (N)	SL (N)
T_1	47.05	2	546	312	T_2	33.34	2	548	390	T_3	29.76	2	590	394
T_1	43.97	4	780	450	T_2	32.36	4	896	582	T_3	26.62	4	772	516
T_1	44.65	6	994	583	T_2	33.97	6	1082	718	T_3	28.41	6	1008	701
T_1	43.95	8	1200	732	T_2	33.85	8	1290	873	T_3	25.85	8	1270	893
T_1	44.11	10	1460	902	T_2	31.27	10	1670	1099	T_3	26.5	10	1536	1127
T_1	44.15	12	1550	936	T_2	34.26	12	2104	1500	T_3	29.04	12	1854	1290
L_1	36.6	2	538	357	L_2	32.02	2	666	456	L_3	25.9	2	762	476
L_1	33.8	4	708	447	L_2	29.25	4	758	528	L_3	26.81	4	1082	718
L_1	33.6	6	952	592	L_2	26.62	6	1032	658	L_3	23.04	6	1402	922
L_1	35.8	8	1172	749	L_2	28.95	8	1370	919	L_3	26.53	8	1900	1318
L_1	35.15	10	1444	937	L_2	30.14	10	1730	1176	L_3	25.27	10	2306	1564
L_1	36.15	12	1742	1149	L_2	27.67	12	2028	1425	L_3	21.93	12	2532	1751
RL_1	25.68	2	642	374	RL_2	20.27	2	704	447	RL_3	16.89	2	868	527
RL_1	27.19	4	852	549	RL_2	18.48	4	1100	660	RL_3	14.44	4	1318	877
RL_1	25.57	6	1132	670	RL_2	20.7	6	1536	993	RL_3	15.33	6	1960	1456
RL_1	25.35	8	1395	838	RL_2	21.22	8	1906	1287	RL_3	15.6	8	2600	1850
RL_1	25.1	10	1606	1071	RL_2	19.81	10	2282	1492	RL_3	14.92	10	3172	2249
RL_1	25.15	12	1890	1266	RL_2	21.17	12	2674	1841	RL_3	13.41	12	3686	2573
ST_1	33.4	2	720	350	ST_2	23.55	2	686	421	ST_3	21.09	2	920	554
ST_1	34.79	4	1036	558	ST_2	24.03	4	1036	671	ST_3	19.68	4	1224	820
ST_1	32.73	6	1356	788	ST_2	25.16	6	1520	967	ST_3	20.62	6	1722	1158
ST_1	30.16	8	1930	1152	ST_2	22.13	8	2398	1594	ST_3	20.51	8	2454	1604
ST_1	29.34	10	2498	1560	ST_2	21.14	10	3322	2267	ST_3	19.27	10	3210	2204
ST_1	30.48	12	2888	1890	ST_2	22.19	12	3620	2501	ST_3	20.02	12	3990	2813
SF_1	27.18	2	726	394	SF_2	20.69	2	834	548	SF_3	19.12	2	978	596
SF_1	26.19	4	1176	631	SF_2	19.61	4	1194	750	SF_3	22.17	4	1792	1090
SF_1	26.04	6	1746	978	SF_2	20.01	6	2314	1471	SF_3	18.9	6	2620	1697
SF_1	25.93	8	2330	1572	SF_2	20.65	8	3250	2180	SF_3	19.86	8	4178	2818
SF_1	25.88	10	2960	1837	SF_2	20.49	10	3788	2629	SF_3	21.66	10	4868	3222
SF_1	25.16	12	3878	2484	SF_2	18.55	12	2518	3625	SF_3	18.4	12	5130	3533
SHT_1	20.07	2	880	456	SHT_2	11.23	2	912	582	SHT_3	10.87	2	1328	888
SHT_1	20.26	4	1528	809	SHT_2	11.93	4	1774	1153	SHT_3	9.58	4	2164	1446
SHT_1	19.37	6	2096	1258	SHT_2	11.44	6	2680	1621	SHT_3	11.69	6	3498	2386
SHT_1	18.79	8	2532	1610	SHT_2	12.48	8	4168	2873	SHT_3	10.06	8	4410	3072
SHT_1	18.04	10	3778	2122	SHT_2	10.82	10	4704	3321	SHT_3	9.46	10	5390	3857
SHT_1	19	12	3776	2529	SHT_2	10.79	12	4956	3426	SHT_3	9.17	12	6344	4542
SHF_1	12.6	2	978	609	SHF_2	6.62	2	1172	729	SHF_3	7.31	2	1172	714
SHF_1	11.68	4	1970	1155	SHF_2	7.78	4	2025	1326	SHF_3	7.02	4	2600	1656
SHF_1	12.2	6	3296	2124	SHF_2	6.8	6	4022	2797	SHF_3	6.32	6	4220	2929
SHF_1	11.27	8	4306	2916	SHF_2	6.59	8	5608	4037	SHF_3	6.63	8	5660	3987
SHF_1	11	10	5586	3824	SHF_2	6.86	10	6580	4705	SHF_3	6.76	10	7094	4990
SHF_1	10.95	12	6436	4448	SHF_2	7.56	12	8578	6750	SHF_3	6.61	12	8342	5787

PE: Pre-extension of fabric for 500N preload; AC: amplitude of cycling; ML: maximum load at first cycle;SL: maximum load at stabilization.

increasing the number of underlaps the cyclic stabilized load is increased (SF2>ST2>L2>T2 and SHF2>SHT2>RL2>T2). This is due to the closer angle between longer uderlap and load direction, and subsequently lower contribution of yarn movement in fabric deformation. Also, the cyclically stabilized load of fabrics with longer underlap in back guide bar is higher than those with the same underlap length in front guide bar (RL2>L2,SHT2>ST2 and SHF2>SF2). It can be attributed to the number of contact points between back guide bar underlp with legs of loops. The number of contact points for Tricot, Locknit, reverse Locknit, three and four needle Sharkskin are 1, 3, 5, and 7, respectively (refer to Figure 1).

C. Holloman's Mathematical Description of Fabric Fatigue

From the Holloman's relation given by $\sigma = K\ \varepsilon^n$, it is possible to mathematically describe the material load-strain response in either the monotonic or cyclically stabilized state. Consequently strain-hardening coefficient for both monotonic (n_1) and cyclic (n_2) conditions and the strength coefficient for both monotonic (K_1) and cyclic (K_2) conditions can be calculated. The strain-hardening

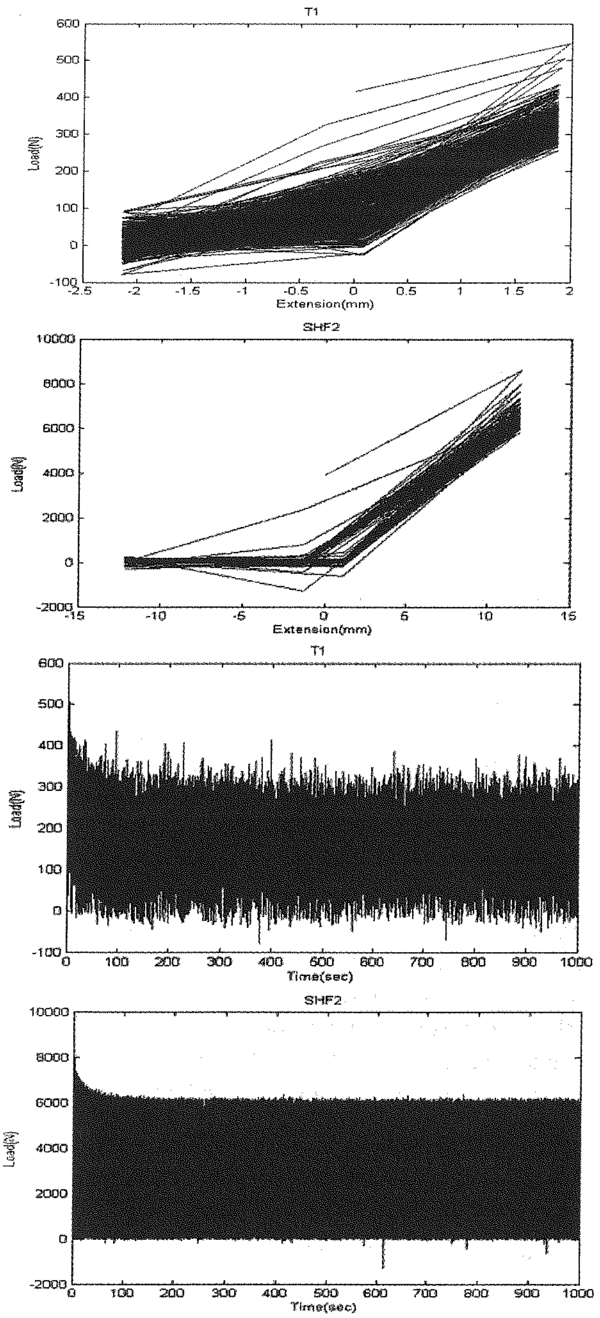

Figure 5: Typical diagrams of load-extension and load-number of cycle of samples T_1 (AC=2mm) and SHF_2 (AC=12mm).

coefficients and strength coefficients of all fabric structures in monotonic and cyclic stabilized conditions are shown in Table 6.

As it can be seen from Table 6, in all fabric structures $K_1>K_2$, it means that cyclic extension causes strain softening in all fabrics. This is due to stress relaxation in fabrics during cyclic extension. Conversely, we can see that in all fabric structures $n_2>n_1$, it means that after cyclic loadingthe elastic property of samples are increased. This is because of the decreasing angle between underlaps and the load direction, and then decreasing the contribution of yarn movement after fatigue process. Also,

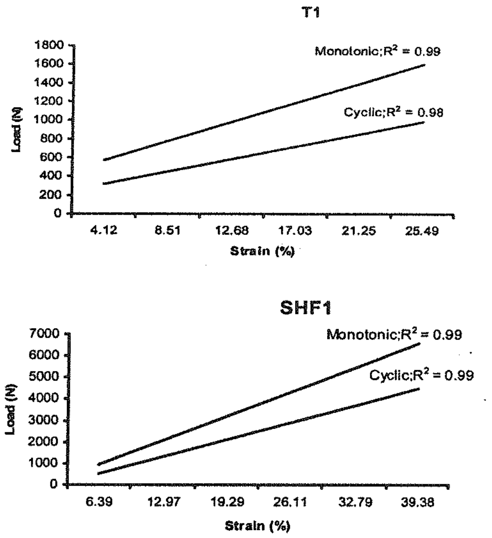

Figure 6: Monotonic and cyclic load-strain regression curves for T1 and SHF1 samples.

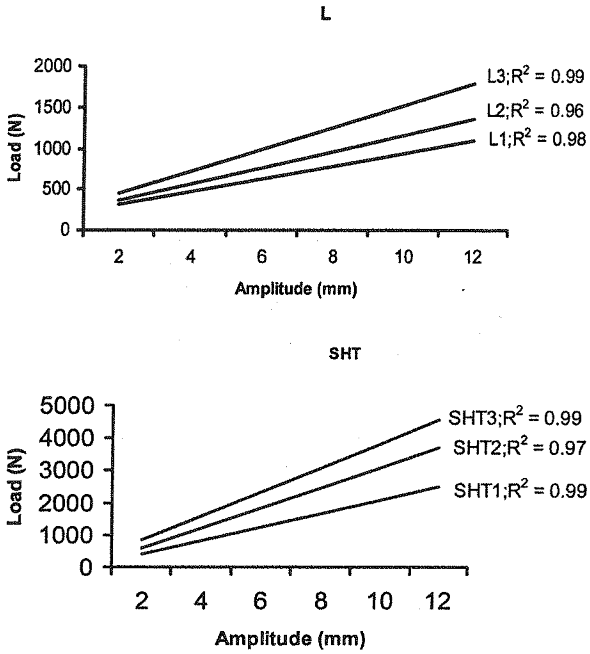

Figure 7: The regression for cyclic stabilized load of fabrics with different cpc at different amplitude of cycling.

during fatigue process, the higher molecular orientation of yarn in fabric structure causes higher elastic property of fabrics.

Figure 9 shows the strain-hardening coefficient of fabrics with different structures. The trend shows that with the increase of underlap length the strain-hardening coefficient of fabrics is increased. This is because of the lower angle between longer underlaps and direction of force and orientation of molecule chain in the yarns. Also, the strain-hardening coefficient in fabrics with longer underlap in back guide bar is higher than those in front guide bar. The explanation of this phenomenon is the same as section 3.B

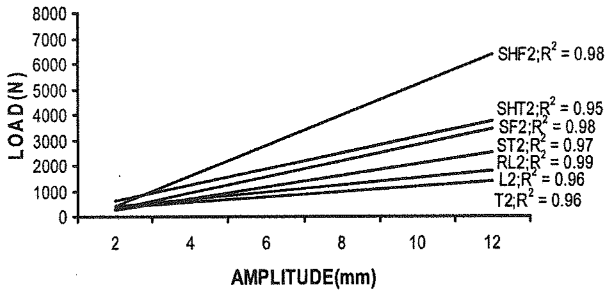

Figure 8: Regression for cyclic stabilized load of fabrics with different structure with nominal cpc 20 at different amplitude of cycling.

TABLE 6

STRENGTH COEFFICIENT AND STRAIN-HARDENING COEFFICIENT OF FABRICS WITH DIFFERENT CPC.

Fabric code	K_1	K_2	n_1	n_2
T_1	271.1	148.4	0.516	0.558
T_2	251.4	155.9	0.596	0.607
T_3	235.9	150.6	0.561	0.591
L_1	220.8	143.3	0.579	0.575
L_2	253.7	173.5	0.566	0.562
L_3	292.5	177.4	0.598	0.633
RL_1	264	145.9	0.542	0.562
RL_2	249.5	148.4	0.645	0.677
RL_3	250.7	188.72	0.71	0.719
ST_1	266.5	121.3	0.659	0.748
ST_2	238.7	125.2	0.723	0.802
ST_3	282.3	167	0.691	0.732
SF_1	242.4	123.4	0.74	0.798
SF_2	237.8	150.1	0.805	0.824
SF_3	313.4	165	0.775	0.838
SHT_1	313.6	145.6	0.667	0.758
SHT_2	269.4	167.1	0.782	0.809
SHT_3	399.9	258.1	0.721	0.745
SHF_1	285.9	168.8	0.813	0.847
SHF_2	288.7	178.5	0.853	0.889
SHF_3	323.3	195.2	0.832	0.869

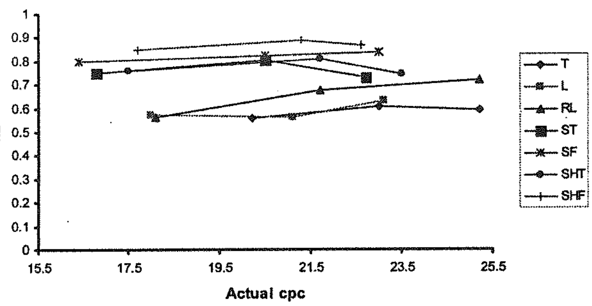

Figure 9: Strain-hardening coefficient of fabrics with different structures.

4. CONCLUSION

In this study, tensile and fatigue behavior of several structures of warp knitted fabrics with three different cpc have investigated. It was shown that the fatigue properties of warp knitted fabrics depend on the structure of fabrics. It seems that the mechanism of the fatigue failure of these fabrics and the cyclic stabilized load can be controlled by the structural parameters of these fabrics, i.e.,: a) The movement space of yarn in fabric structure, and b) the length of underlaps.

The breaking strain of fabrics decreases with the increase of underlap length, while breaking tenacity will increase, and breaking strain in fabrics with longer underlap in front guide bars is more than fabrics with the same length of underlaps in back guide bars conversely, the breaking tenacity of fabrics with longer underlap in back guide bar is more than the fabrics with the same length in front guide bar.

Cyclic extension causes stress relaxation in warp knitted fabrics and the maximum load in each cycle decreases as the number of cycle is increased and the maximum load reaches to a constant amount as **cyclic stabilized load**. The results show that the cyclic extension causes strain softening in all fabrics.

To asses mathematically the behavior of fabrics before and after cyclic loading, the Holloman's relation ($\sigma = K\,\varepsilon^n$) has been applied. The results show that in all fabrics, the strength coefficient decreased after cyclic loading ($K_1>K_2$) and conversely, the strain-hardening coefficient is increased ($n_2>n_1$). Comparison of fabrics with different structure shows that, by increasing the underlap length, the strain-hardening coefficient is increased, also the strain-hardening coefficient of fabrics with longer underlap in back guide bar is higher than the fabrics of the same length of underlap in front guide bar. Therefore, it can be concluded that the Holloman's relation is a good approach to explain the fatigue behavior of warp knitted fabrics.

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