Investigation of Fatigue Behavior of Polyester Filament Woven Fabrics under Cyclic Loading

Hooshang Nosraty, Ali Asghar Asgharian Jeddi and Raha Saremi

Abstract—**In this research, the effect of cyclic loading values, stroke value and weft density on the mechanical properties of woven fabrics is investigated. Six different woven fabrics, plain, rib 2/2, twill 1/3, twill 1/7, satin 1/7 and herringbone twill, with three different weft densities, are produced from polyester filament warp and weft yarns. Samples are then subjected to the fatigue test in warp wise and weft wise directions, under two stroke levels and four loading cycle values. The results indicate that, the trend of mechanical properties changes due to cyclic loading is approximately same for all fabrics. Increasing of cyclic loading increases the value of second modulus of fabrics and decreases the value of tensile strain of the samples while the maximum load of samples does not change. Besides, the increasing of fabric weft density raises the measured mechanical properties of all samples. Increasing of stroke value causes the increase in the second modulus and decreasing the tensile strain of fabrics and has no significant effect on the maximum load.**

Key words: Woven fabrics, cyclic loading, fatigue, maximum load, tensile strain, second modulus.

I. INTRODUCTION

TEXTILES have been found wide applications in different industries not limited to apparels in modern world. Fatigue due to cyclic loading is one of the most important factor in the non-conventional usages of textiles. Obviously such issue is not limited to such type of application and the fatigue of textile materials is also very important issue for the classical textile processing such as weaving.

The expression of "fatigue" was used first in 1839 [1]. This word means exhaustion, fracture, abrasion, erosion and toil in vocabulary and in textile and polymer engineering it is used for expression of change in the properties of material under cycle loading [2]. Fatigue is the failure or decay of mechanical properties after repeated tensions. Fatigue tests give some information about the ability of material to withstand cracking which results in fracture after some cycles [3].

The fatigue behavior of fibers has been studied for many years. Researchers have considered several theories about the fibers fatigue [4-12]. Some studies have provided information on the yarn fatigue [13-15], while some have focused on fabric fatigue. In performed studies on fatigue behavior of fabrics, Abdessalem *et al.* [16] discussed on the effect of fatigue behavior of weft knitted fabric from cotton on stitch geometry by implementation image processing technique. They observed that repeated elongation which was involved by permanent deformation widely depends on the relaxation and the number of loading cycles.

The effect of warp knitted fabric structure on the mechanical properties under cycling loading was studied by Jeddi *et al.* [17]. For this purpose, uniaxial tensile fatigue tester with a single station was designed and used for fatigue tests. They reported that geometry of fabric structure affects on the fabric fatigue behavior and the final deformation and modulus of the fabrics increase by increasing the number of fatigue loading cycles, while the percentage of tensile breaking elongation decreases. Taheri Otaghsara *et al.* [18] investigated the fatigue behavior of warp knitted fabrics under the cyclic extension using Holloman's relation. They investigated that the increase in the underlap length leads to a decrease in the breaking extension percent and increase in the breaking tenacity. In another study, the tensile and fatigue behavior of different structures of warp knitted fabrics with different course density was investigated by Taheri Otaghsara *et al.* [19]. The results showed that the structural parameters have an influence on the tensile and fatigue properties of warp knitted fabrics.

Asayesh and Jeddi [20] studied the tensile fatigue behavior of woven fabrics made of polyester textured filament yarn. In this research, the plain woven fabrics with different weft densities were produced and the viscoelastic properties of samples at 1% strain with 1Hz frequency and 0.5% strain with 3Hz frequency were measured. They found that, the yarn slippage in the fabric occurs at the beginning of the test and with increasing the weft density, fabric storage modulus and loss modulus increase for all testing conditions. Asayesh *et al.* [21] investigated fatigue behavior of plain woven fabrics by using the yarn fatigue property and the structural-mechanical parameters of the fabric. For this purpose, the Eyring viscoelastic model was developed as a theoretical background to predict the fabric elongation in a constant cyclic load status. They observed that, with increasing the weft density, fabric fatigue decreases. Tarafder *et al.* [22, 23] measured the effect of percentage of wool and polyester in their blends in the structure of fabric under fatigue test on the physical and mechanical properties of fabrics.

The aim of this study is to investigate the effect of cyclic

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loading numbers, stroke value and weft density on the mechanical properties of different structures of woven fabrics subjected to the fatigue test in warp wise and weft wise directions.

II. EXPERIMENTAL

In this research, six woven structures, plain, rib 2/2, twill 1/3, twill 1/7, satin 1/7 and herringbone twill with three different weft densities, 18, 22 and 26 picks/cm, were produced from polyester textured filament yarn with 150 denier count for warp yarn and 80 denier count for weft yarn on a dobby projectile loom. Characteristics of warp and weft filament polyester yarns are shown in Table I. Characteristics of woven fabrics are shown in Table II.

TABLE I
SPECIFICATIONS OF WARP AND WEFT FILAMENT POLYESTER YARNS

Twist (TPM)	Breaking extension (%)	Breaking tenacity (cN/tex)	Count (den)	Yarn
400z	29.00	36.11	150	Warp
20z	25.11	35.55	80	Weft

Fatigue test was normally done according to the following two methods, i.e. the controllable parameter was the sample tension with constant tension amplitude and the controllable parameter was the sample strain in the direction of loading. In this method the, sample was subjected to cyclic loading with constant strain amplitude [24].

TABLE II
FABRIC CHARACTERISTICS

Weft density (picks/cm)	Structure	Fabric code
18	plain	P(18)
22	plain	P(22)
26	plain	P(26)
18	rib 2/2	R(18)
22	rib 2/2	R(22)
26	rib 2/2	R(26)
18	twill 1/3	T1/3(18)
22	twill 1/3	T1/3(22)
26	twill 1/3	T1/3(26)
18	twill 1/7	T1/7(18)
22	twill 1/7	T1/7(22)
26	twill 1/7	T1/7(26)
18	satin 1/7	S(18)
22	satin 1/7	S(22)
26	satin 1/7	S(26)
18	herringbone twill	H(18)
22	herringbone twill	H(22)
26	herringbone twill	H(26)

We used the second method on the fatigue testing apparatus, which was designed in the previous work [17]. A schematic diagram of the cyclic loading apparatus is shown in Figure 1.

For flexibility, the equipments were designed in a way that they provide possibility to change the value of frequency, stroke in each cycle, sample length and exerted force to the fabrics. In this apparatus, the maximum value of frequency was 115 cycle/min, the maximum value of stroke was 10 cm and the range of sample length was 15 to 25 cm. Also by adjusting the supplied air pressure with a regulator into the cylinders, the exerted force on the sample was controlled.

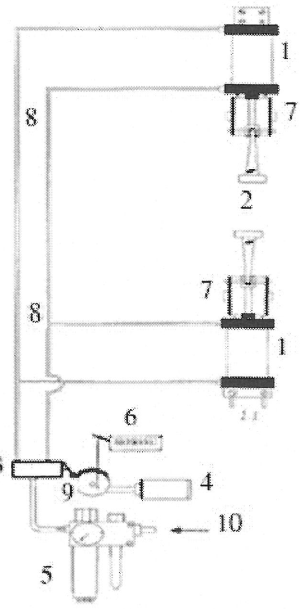

Fig. 1. Schematic diagram of cyclic loading apparatus [25].

1. *A pair of pneumatic cylinders and pistons for provide the vertical motion*
2. *Jaws for holding the fabric sample*
3. *The air valve which activating by an electro motor and using to change the air flow direction in the cylinders*
4. *Electromotor*
5. *Air pressure regulator*
6. *The counter for recording the number of loading cycles*
7. *Restraint pieces, in order to increase the ability of the apparatus to provide different strokes on the specimens. Four restraint pieces using adjust this displacement*
8. *Connections*
9. *A cam system for changing the air flow direction in the cylinders*
10. *Air channel for supplied compressed air flow*
11. *Adjustment point of lower cylinder in order to the gauge length of the specimen could be varied between 15 and 25 cm.*

Thereafter, the fatigue tests were performed on 18 samples of woven fabrics with two strokes levels 12% and 18% corresponding to sample length and four loading cycles, 1000, 4000, 8000 and 12000. The frequency of experiments was 100±3 cycles/min and sample length and sample width were 20 cm and 5 cm respectively. In each state of experiments, two samples were performed in warp wise and weft wise directions under cyclic loading so that totally 576 fabric samples were tested. Afterward, the mechanical properties, i.e. the maximum load, tensile strain and the fabric second modulus of each tested sample were measured by Instron tensile tester according to related standards.

TABLE III
THE AVERAGE OF MECHANICAL PROPERTIES OF FABRICS AFTER DIFFERENT LOADING CYCLES

Fabric Code	Stroke (%)	Number of Loading Cycles	Maximum Load(N)		Tensile Strain (%)		Second Modulus(N)	
			Warp wise	Weft wise	Warp wise	Weft wise	Warp wise	Weft wise
P(18)	12	0	826.05	216.33	22.59	20.33	86.87	18.00
	12	1000	828.60	218.27	16.67	18.50	100.00	20.23
	12	4000	830.50	208.07	16.25	16.25	102.50	21.00
	12	8000	834.97	222.31	16.00	15.00	105.00	22.22
	12	12000	820.10	221.84	15.00	14.17	112.00	23.08
P(22)	12	0	856.42	291.60	24.44	25.00	100.41	22.00
	12	1000	846.74	291.74	18.33	20.84	105.00	25.83
	12	4000	852.82	286.88	16.67	17.67	112.00	27.50
	12	8000	852.10	286.92	16.50	16.17	115.00	30.78
	12	12000	862.15	276.58	16.00	15.83	125.00	32.00
P(26)	12	0	873.12	330.00	25.67	31.58	107.00	30.00
	12	1000	864.10	332.74	20.00	23.75	110.00	36.67
	12	4000	861.00	319.11	19.17	22.50	115.00	38.78
	12	8000	875.00	320.75	18.75	20.17	120.00	40.08
	12	12000	885.00	353.48	17.50	18.17	143.00	44.00
P(18)	18	0	826.05	216.33	22.59	20.33	86.87	18.00
	18	1000	835.40	223.98	13.75	15.25	100.00	25.00
	18	4000	850.42	225.98	12.17	12.92	105.00	27.00
	18	8000	840.62	219.21	11.35	10.17	110.00	29.98
	18	12000	833.29	213.46	11.67	8.67	115.00	31.33
P(22)	18	0	856.42	291.60	24.44	25.00	100.41	22.00
	18	1000	869.90	297.66	15.00	17.25	114.29	27.83
	18	4000	879.61	283.30	13.75	15.00	120.00	29.27
	18	8000	898.88	293.87	13.33	14.59	130.00	33.00
	18	12000	898.02	288.63	13.00	13.33	140.00	35.08
P(26)	18	0	883.12	330.00	25.67	31.58	125.00	30.00
	18	1000	885.66	340.08	16.08	20.00	140.00	35.25
	18	4000	896.59	342.17	15.83	19.17	145.33	37.43
	18	8000	910.05	340.00	14.17	18.00	150.95	39.35
	18	12000	923.12	343.76	13.92	16.67	170.00	41.71
R(18)	12	0	752.19	194.88	24.00	17.67	54.84	17.93
	12	1000	731.58	187.87	19.17	13.50	60.00	22.75
	12	4000	743.59	193.33	18.75	13.33	62.50	25.00
	12	8000	747.11	196.92	18.33	12.50	73.33	28.50
	12	12000	760.26	195.72	18.00	11.67	82.00	30.00
R(22)	12	0	761.05	266.61	27.09	19.67	65.00	28.00
	12	1000	750.22	246.95	21.67	16.67	66.67	27.78
	12	4000	757.28	249.68	20.83	16.00	85.00	30.00
	12	8000	766.42	264.68	20.00	14.17	90.33	33.33
	12	12000	771.15	260.83	18.83	13.33	100.00	40.77
R(26)	12	0	800.43	313.33	28.50	21.67	75.51	37.53
	12	1000	812.01	302.21	25.17	18.00	83.33	45.00
	12	4000	760.16	306.77	21.83	17.00	92.27	48.89
	12	8000	767.06	312.43	21.05	16.00	100.11	50.00
	12	12000	777.20	309.18	20.00	16.50	104.29	52.00
R(18)	18	0	752.19	194.88	24.00	17.67	54.84	17.93
	18	1000	754.76	190.00	16.67	9.58	66.67	20.00
	18	4000	771.77	207.79	15.42	9.00	70.00	25.00
	18	8000	741.69	200.00	14.17	8.11	75.24	30.00
	18	12000	743.75	199.36	14.00	7.67	85.00	30.29
R(22)	18	0	761.05	266.61	27.09	19.67	65.00	28.00
	18	1000	779.74	266.96	18.75	11.00	80.00	30.00
	18	4000	793.89	260.83	17.50	10.00	90.00	32.00
	18	8000	777.08	278.86	15.00	9.50	98.00	34.00
	18	12000	752.36	273.32	14.17	9.00	105.00	36.00

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TABLE III
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Fabric Code	Stroke (%)	Number of Loading Cycles	Maximum Load(N)		Tensile Strain (%)		Second Modulus(N)	
			Warp wise	Weft wise	Warp wise	Weft wise	Warp wise	Weft wise
R(26)	18	0	800.43	313.33	28.50	21.67	75.51	37.53
	18	1000	804.74	311.95	20.15	12.00	85.00	38.50
	18	4000	793.62	317.18	18.17	11.25	95.00	45.00
	18	8000	782.45	331.12	17.50	10.83	102.00	50.00
	18	12000	792.89	324.01	15.00	10.00	110.00	58.33
T1/3(18)	12	0	861.20	184.24	25.50	22.00	70.00	12.50
	12	1000	862.67	175.03	20.00	16.33	75.00	16.67
	12	4000	855.00	181.42	19.17	15.92	83.33	17.67
	12	8000	855.99	180.49	17.50	14.83	92.86	18.00
	12	12000	840.99	163.77	17.00	14.09	105.00	18.27
T1/3(22)	12	0	934.00	232.56	27.00	25.00	75.80	16.20
	12	1000	889.50	239.51	20.83	19.33	90.91	17.67
	12	4000	868.83	233.69	20.07	19.17	100.00	18.50
	12	8000	895.40	228.89	19.00	16.50	110.00	20.00
	12	12000	920.02	225.14	18.33	15.67	114.29	21.50
T1/3(26)	12	0	946.00	288.00	28.67	28.09	111.10	18.00
	12	1000	921.60	288.31	22.08	23.33	112.50	20.00
	12	4000	922.40	282.43	21.67	21.67	125.00	21.00
	12	8000	907.55	281.82	21.00	21.17	128.00	22.00
	12	12000	951.86	282.46	20.00	19.67	150.00	23.08
T1/3(18)	18	0	861.20	184.24	25.50	22.00	70.00	12.50
	18	1000	856.36	164.74	16.25	13.58	83.33	16.67
	18	4000	879.61	170.71	15.00	13.00	85.71	20.83
	18	8000	871.20	162.96	14.17	12.83	93.33	22.22
	18	12000	860.15	167.63	13.33	11.33	108.00	23.22
T1/3(22)	18	0	934.00	232.56	27.00	25.00	75.80	16.20
	18	1000	891.59	217.00	17.50	16.25	93.33	18.18
	18	4000	881.43	226.99	17.00	15.08	104.89	24.50
	18	8000	917.32	217.85	16.67	14.42	113.33	25.71
	18	12000	915.97	224.14	15.00	12.35	115.00	26.67
T1/3(26)	18	0	946.00	288.00	28.67	28.09	111.10	18.00
	18	1000	913.05	264.21	22.92	17.17	116.67	25.00
	18	4000	920.30	273.08	18.33	17.00	125.29	28.57
	18	8000	941.60	264.74	18.67	16.34	146.67	33.33
	18	12000	964.17	279.58	16.00	16.00	152.50	35.71
T1/7(18)	12	0	880.00	146.51	24.50	19.50	70.00	11.20
	12	1000	920.03	147.91	20.83	15.50	78.00	14.83
	12	4000	875.90	135.41	20.00	15.09	82.67	15.00
	12	8000	927.42	138.77	18.50	14.17	88.33	16.29
	12	12000	942.21	139.43	18.33	13.00	97.31	17.86
T1/7(22)	12	0	958.94	187.26	25.42	21.00	80.00	14.00
	12	1000	936.54	185.69	22.92	17.50	90.00	16.67
	12	4000	927.32	175.57	22.08	16.67	105.00	17.00
	12	8000	965.22	174.84	21.67	16.00	105.50	19.00
	12	12000	941.48	171.30	20.83	15.58	120.00	20.22
T1/7(26)	12	0	976.54	233.86	26.67	25.00	97.50	18.31
	12	1000	940.25	219.94	23.33	18.83	105.00	19.75
	12	4000	962.88	229.54	22.92	18.00	120.77	20.00
	12	8000	959.31	236.33	22.08	17.92	135.00	23.18
	12	12000	953.83	217.03	21.67	17.17	135.00	25.00
T1/7(18)	18	0	880.00	146.51	24.50	19.50	70.00	11.20
	18	1000	900.02	140.14	17.50	14.67	79.27	14.67
	18	4000	902.39	144.98	16.25	12.92	83.00	18.18
	18	8000	886.00	134.72	15.83	11.84	90.33	19.83
	18	12000	924.13	140.91	15.00	9.17	100.00	20.00

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Fabric Code	Stroke (%)	Number of Loading Cycles	Maximum Load(N)		Tensile Strain (%)		Second Modulus(N)	
			Warp wise	Weft wise	Warp wise	Weft wise	Warp wise	Weft wise
T1/7(22)	18	0	958.94	187.26	25.42	21.00	80.00	14.00
	18	1000	944.32	171.83	19.17	15.83	100.00	16.65
	18	4000	942.78	183.33	17.92	14.33	105.00	22.67
	18	8000	932.66	186.83	17.50	14.00	110.00	24.00
	18	12000	972.34	175.44	17.00	11.00	125.00	26.00
T1/7(26)	18	0	976.54	233.86	26.67	25.00	97.50	18.31
	18	1000	981.43	248.94	21.67	17.00	122.00	23.00
	18	4000	950.96	244.65	21.00	15.67	132.50	26.67
	18	8000	956.49	255.22	19.17	15.07	135.71	27.50
	18	12000	998.76	254.89	17.92	14.00	138.00	30.71
S(18)	12	0	827.96	173.99	26.00	20.25	60.60	15.14
	12	1000	837.73	162.80	22.92	18.92	67.14	17.64
	12	4000	848.36	166.33	21.67	18.58	80.00	20.00
	12	8000	850.92	166.25	20.83	16.67	83.33	21.00
	12	12000	831.10	158.74	20.50	15.00	85.33	21.67
S(22)	12	0	851.32	215.69	27.25	22.00	73.33	17.50
	12	1000	860.63	200.22	24.67	19.58	86.96	25.00
	12	4000	855.75	192.44	23.00	19.50	91.66	25.50
	12	8000	866.97	200.94	22.07	18.33	100.00	26.14
	12	12000	874.28	202.11	21.50	17.00	105.00	28.57
S(26)	12	0	880.98	295.00	29.50	26.00	88.57	28.03
	12	1000	885.29	258.92	26.75	20.83	95.00	29.67
	12	4000	895.91	245.67	24.33	20.25	100.00	30.71
	12	8000	899.16	253.20	23.50	19.17	103.33	31.25
	12	12000	879.29	244.51	22.50	17.83	108.35	35.71
S(18)	18	0	827.96	173.99	26.00	20.25	60.60	15.14
	18	1000	842.48	175.13	18.33	15.75	75.00	18.75
	18	4000	840.80	177.07	17.50	14.58	90.00	21.43
	18	8000	831.06	178.91	16.67	12.50	95.00	22.73
	18	12000	835.06	194.17	16.25	11.67	100.00	25.00
S(22)	18	0	851.32	215.69	27.25	22.00	73.33	17.50
	18	1000	855.70	234.08	18.75	16.83	86.96	22.22
	18	4000	870.10	230.73	18.33	16.00	91.66	27.78
	18	8000	872.77	247.65	17.92	15.83	100.00	29.17
	18	12000	883.58	252.00	17.50	14.50	105.00	31.25
S(26)	18	0	880.98	295.00	29.50	26.00	88.57	28.03
	18	1000	894.44	299.39	21.58	19.33	112.00	35.77
	18	4000	912.43	299.09	20.17	17.00	113.64	37.50
	18	8000	915.71	313.52	19.00	16.67	120.00	40.00
	18	12000	939.43	300.72	18.50	15.00	136.36	50.00
H(18)	12	0	815.00	158.01	24.42	24.09	75.00	12.50
	12	1000	801.79	154.98	20.00	20.00	80.33	13.00
	12	4000	805.89	148.98	18.75	18.67	83.33	13.50
	12	8000	771.21	153.43	18.33	18.50	85.00	14.00
	12	12000	810.75	152.39	18.00	18.34	88.57	17.00
H(22)	12	0	825.15	224.56	25.42	25.50	85.00	18.18
	12	1000	832.48	221.87	21.42	22.50	95.45	18.75
	12	4000	839.50	204.73	20.08	21.00	100.00	19.44
	12	8000	834.97	211.39	19.17	18.92	102.00	22.00
	12	12000	842.41	209.58	19.00	18.83	106.67	22.67
H(26)	12	0	894.51	275.08	27.08	26.67	95.00	20.12
	12	1000	892.36	275.16	22.08	25.00	100.00	25.00
	12	4000	911.70	268.29	21.67	23.75	103.00	26.67
	12	8000	894.08	276.25	20.00	23.09	105.00	27.50
	12	12000	889.45	255.23	19.50	21.67	115.00	33.33

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Fabric Code	Stroke (%)	Number of Loading Cycles	Maximum Load(N)		Tensile Strain (%)		Second Modulus(N)	
			Warp wise	Weft wise	Warp wise	Weft wise	Warp wise	Weft wise
H(18)	18	0	815.00	158.01	24.42	24.09	75.00	12.50
	18	1000	774.83	154.04	15.83	17.00	80.33	18.18
	18	4000	784.48	151.76	15.42	15.67	83.33	20.00
	18	8000	759.44	148.66	15.00	15.17	85.00	25.00
	18	12000	766.16	149.43	14.58	15.00	88.57	28.57
H(22)	18	0	825.15	224.56	25.42	25.50	85.00	18.18
	18	1000	822.01	209.50	22.50	19.50	97.22	25.00
	18	4000	854.68	210.46	18.33	18.00	100.00	26.33
	18	8000	799.56	217.01	16.67	16.67	105.00	28.57
	18	12000	802.50	213.07	15.42	15.50	120.00	33.33
H(26)	18	0	894.51	275.08	27.08	26.67	95.00	20.12
	18	1000	859.38	276.52	23.50	20.00	100.00	30.00
	18	4000	875.80	265.37	19.50	18.67	105.00	33.33
	18	8000	884.07	268.90	18.67	17.00	110.50	34.55
	18	12000	891.60	260.37	16.67	16.17	130.00	41.67

III. RESULTS AND DISCUSSION

The mechanical properties of all fabric structures with different weft densities (18, 22 and 26 picks/cm) at 12% and 18% strokes were averaged from 5 samples and are shown in Table III.

Based on the results reported in Table III and the plotted diagrams [26], it was found that the trends of variation in the measured mechanical properties are approximately same for all six fabrics. Therefore, as shown in Figures 2 to 5, the diagrams of plain fabric were taken as typical diagrams of maximum load, tensile strain and second modulus of plain fabric at 18% stroke.

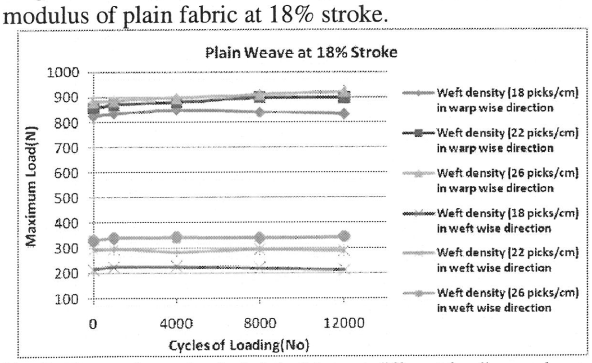

Fig. 2. The maximum load of plain fabric at different loading cycles and 18% stroke.

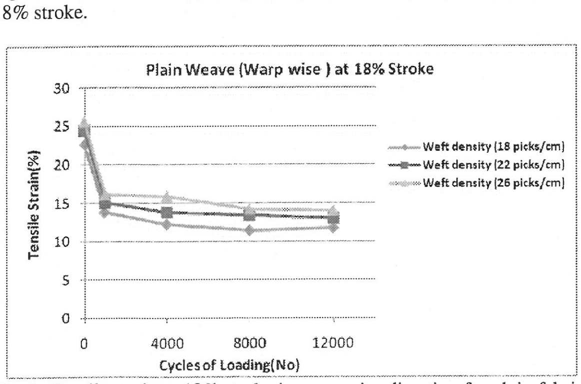

Fig. 3. Tensile strain at 18% stroke in warp wise direction for plain fabric.

A. *Effect of cyclic loading on the mechanical properties of fatigued fabric*

In this study, the statistical analysis (ANOVA) was done for both 12% and 18% strokes in weft and warp wise directions. Results of statistical analysis for cyclic loading in warp and weft wise directions are shown in Table IV. As this table shows, the increasing of number of loading cycles has no significant effect on the maximum load of samples both in warp and weft wise directions. In the consequence of the cyclic loading the two changes were observed. First, the orientation of yarns in fabrics structure increased with increasing of loading cycle's number. Besides, the rupture of filament yarns was occurred. The first issue causes to increase the value of maximum load and the second phenomenon causes to decrease the value of fabrics maximum load [25]. Accordingly, some variations in fabric's maximum load could not be seen. It seems that if the loading cycle is increased to the range greater than 12000, the maximum load of fabrics would be less. Indeed, by increasing of cycling loading values it seems that in the first phase, the hardening phenomena of fibres structure takes places that includes more second modulus and less strain. Decreasing of mechanical characteristics of samples would be expected by repeating the cycling loading with enough cycle numbers that means the occurrence of fatigue phenomena.

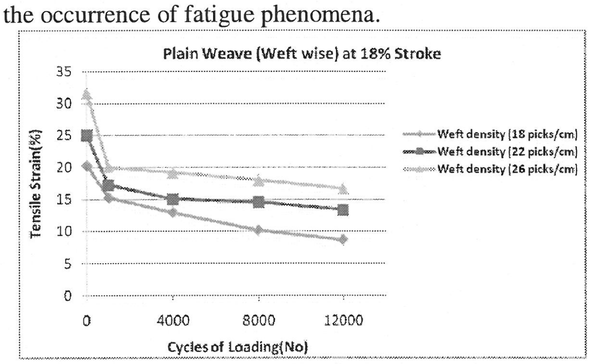

Fig. 4. Tensile strain at 18% stroke in weft wise direction for plain fabric.

TABLE IV
ANOVA RESULTS FOR THE EFFECT OF CYCLIC LOADING IN WARP AND WEFT WISE DIRECTIONS

		Sum of Squares	df	Mean Square	F	Sig.
Maximum Load (warp wise)	Between Groups	4313.125	4	1078.281	.267	.899
	Within Groups	1287899.826	319	4037.304		
	Total	1292212.951	323			
Second Modulus (warp wise)	Between Groups	35365.487	4	8841.372	27.495	.000
	Within Groups	102578.117	319	321.561		
	Total	137943.603	323			
Tensile Strain (warp wise)	Between Groups	2196.292	4	549.073	71.122	.000
	Within Groups	2462.725	319	7.720		
	Total	4659.017	323			
Maximum Load (weft wise)	Between Groups	2111.850	4	527.962	.176	.951
	Within Groups	955566.850	319	2995.507		
	Total	957678.699	323			
Second Modulus (weft wise)	Between Groups	2134.992	4	533.748	46.484	.000
	Within Groups	3662.888	319	11.482		
	Total	5797.880	323			
Tensile Strain (weft wise)	Between Groups	3761.509	4	940.377	14.074	.000
	Within Groups	21314.791	319	66.818		
	Total	25076.299	323			

The trend of variations of mechanical properties of tested fabrics showed that the increasing of loading cycle number leads to decreasing of fabrics tensile strains and the results are shown in Figures 3 and 4. The statistical analysis results show that cyclic loading has the significant effect on the tensile strain of fabric samples that indicates to the fatigue of samples under repetitive loading. Indeed, with increasing the number of loading cycles imposed on samples, the rate of fatigue development increased. Duncan results showed that the tensile strain decreases with the increasing of the number of loading cycles and the results are same in warp and weft wise directions.

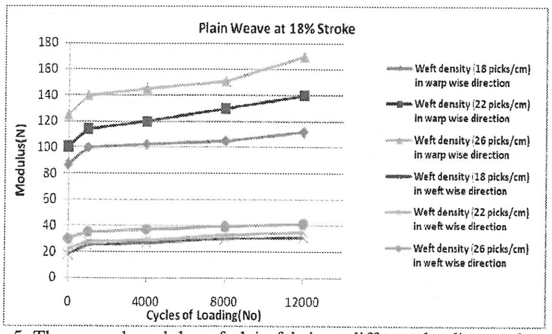

Fig. 5. The second modulus of plain fabric at different loading cycles and 18% stroke.

To obtain the second modulus of fabrics in this study, the results of load–strain diagrams measured by Instron were taken. In fact, the slope angles after the nonlinear area for all samples were chosen and considered as the second modulus of each sample [17]. Figure 6 shows the determined second modulus that is really equal to tangent of α angle:

$$\text{Second modulus} = \tan\alpha = \frac{\text{Load(N)}}{\text{TensileStrain(\%)}} \quad (1)$$

The statistical analysis results indicated that the cyclic loading has a significant effect on the second modulus of fabric samples for both warp and weft wise directions. Table IV shows the results of the analysis. Figure 5 and the results of Duncan analysis shows that by increasing the loading cycle's number the second modulus of fabric samples increases. It can be attributed to the better orientation of polymer chains in the yarns that form the fabrics structure [12].

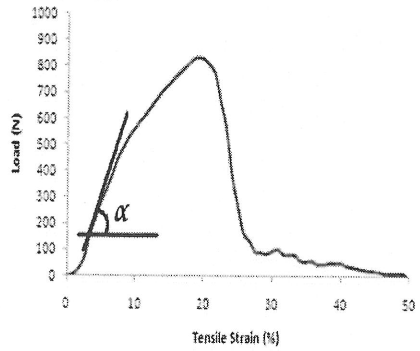

Fig. 6. Typical load–strain diagram of woven fabrics

B. Effect of the weft density on the mechanical properties of fatigued fabrics

It is clear that with increasing the weft density, the maximum load, tensile strain and second modulus increase

TABLE V
ANOVA RESULTS FOR THE EFFECT OF WEFT DENSITY IN WARP AND WEFT WISE DIRECTIONS

		Sum of Squares	df	Mean Square	F	Sig.
Maximum Load (warp wise)	Between Groups	205919.352	2	102959.676	30.425	.000
	Within Groups	1086293.599	321	3384.092		
	Total	1292212.951	323			
Second Modulus (warp wise)	Between Groups	48765.495	2	24382.748	87.767	.000
	Within Groups	89178.108	321	277.813		
	Total	137943.603	323			
Tensile Strain (warp wise)	Between Groups	529.691	2	264.845	20.588	.000
	Within Groups	4129.326	321	12.864		
	Total	4659.017	323			
Maximum Load (weft wise)	Between Groups	583638.103	2	291819.051	250.438	.000
	Within Groups	374040.597	321	1165.236		
	Total	957678.699	323			
Second Modulus (weft wise)	Between Groups	947.262	2	473.631	31.344	.000
	Within Groups	4850.618	321	15.111		
	Total	5797.880	323			
Tensile Strain (weft wise)	Between Groups	8365.468	2	4182.734	80.347	.000
	Within Groups	16710.832	321	52.059		
	Total	25076.299	323			

TABLE VI
ANOVA RESULTS FOR THE EFFECT OF STROKE VALUE IN WARP AND WEFT WISE DIRECTIONS

		Sum of Squares	df	Mean Square	F	Sig.
Maximum Load (warp wise)	Between Groups	3975.986	2	1987.993	.495	.610
	Within Groups	1288236.964	321	4013.199		
	Total	1292212.951	323			
Second Modulus (warp wise)	Between Groups	20421.158	2	10210.579	27.889	.000
	Within Groups	117522.445	321	366.114		
	Total	137943.603	323			
Tensile Strain (warp wise)	Between Groups	2676.026	2	1338.013	216.593	.000
	Within Groups	1982.991	321	6.178		
	Total	4659.017	323			
Maximum Load (weft wise)	Between Groups	2777.851	2	1388.925	.467	.627
	Within Groups	954900.849	321	2974.769		
	Total	957678.699	323			
Second Modulus (weft wise)	Between Groups	2607.984	2	1303.992	131.221	.000
	Within Groups	3189.896	321	9.937		
	Total	5797.880	323			
Tensile Strain (weft wise)	Between Groups	2633.400	2	1316.700	18.833	.000
	Within Groups	22442.900	321	69.916		
	Total	25076.299	323			

TABLE VII
ANOVA RESULTS FOR THE EFFECT OF FABRIC STRUCTURE IN WARP AND WEFT WISE DIRECTIONS

		Sum of Squares	df	Mean Square	F	Sig.
Maximum Load (warp wise)	Between Groups	914745.568	5	182949.114	154.127	.000
	Within Groups	377467.382	318	1187.004		
	Total	1292212.951	323			
Second Modulus (warp wise)	Between Groups	37008.085	5	7401.617	23.319	.000
	Within Groups	100935.518	318	317.407		
	Total	137943.603	323			
Tensile Strain (warp wise)	Between Groups	735.733	5	147.147	11.927	.000
	Within Groups	3923.284	318	12.337		
	Total	4659.017	323			
Maximum Load (weft wise)	Between Groups	246923.949	5	49384.790	22.095	.000
	Within Groups	710754.750	318	2235.078		
	Total	957678.699	323			
Second Modulus (weft wise)	Between Groups	1297.950	5	259.590	18.345	.000
	Within Groups	4499.930	318	14.151		
	Total	5797.880	323			
Tensile Strain (weft wise)	Between Groups	8507.424	5	1701.485	32.656	.000
	Within Groups	16568.875	318	52.103		
	Total	25076.299	323			

in the weft wise due to the existence of more picks against loading direction. AS Table V shows, the statistical analysis results showed that the weft density has the significant effect on the mechanical properties of fabrics in both warp and weft wise directions. As expected, the increasing of the weft density caused a more dense fabric that reasonably led to higher mechanical properties.

C. *Effect of the stroke value on the mechanical properties of fatigued fabric*

The statistical analysis on the results obtained from the effect of stoke value on the mechanical properties of fatigued samples showed that the stork value does not affect the fabrics' maximum load in both warp and weft wise directions. However, as Table VI shows it has a significant effect on the tensile strain and the second modulus. In fact, with increasing the stroke, there is not much difference between the fabrics' maximum load in both warp and weft wise directions. By increasing the stroke two phenomena take place, i.e. the orientation of yarns in fabrics structure increases at first step and then tearing of filament yarns happens. The first issue causes to increase of the value of maximum load while the second phenomenon results in the decrease of the value of fabrics maximum load. Therefore, significant variation in fabrics' maximum load due to stroke variation could not be expected [25].

The stroke factor has a significant effect on the tensile strain of samples and by increasing of it, the tensile strain of fabrics in both warp wise and weft wise directions decreases. The orientation of polymer chains in the yarns increases with the increasing of stroke factor that leads to less movement of yarns in the fabric. Hence, the fabric is broken under lower tensile strain loading [12].

Results of Duncan test showed that the second modulus at 18% stroke is more than the second modulus at 12% stroke for both warp and weft wise directions. This result relates to the better orientation of polymer chains in the yarns in fabric structures when the stroke is increased to 18% [12].

D. *Effect of fabric structure on the mechanical properties of fatigued fabric*

Results of statistical analysis on the effect of fabrics' structure in the warp and weft wise directions are shown in Tables VII. The statistical analysis results show that the structure has a significant effect on the mechanical properties of fabrics in both warp and weft wise directions.

Duncan test indicated that twill 1/7 weave and rib 2/2 weave have the maximum and the minimum values of maximum load in warp wise direction, respectively. In weft wise direction, twill 1/7 weave and plain weave have respectively the minimum and maximum values of maximum load.

The results of Duncan statistical analysis showed that in warp and weft wise directions satin 1/7 weave and herringbone twill weave have the maximum values while, the plain weave and rib 2/2 have the minimum values in tensile strain, respectively.

Statistical analysis showed that the fabric structure has the significant effect on the sample second modulus. In addition, Duncan test showed that in warp wise and weft wise directions plain and rib 2/2 weaves have the maximum values and rib 2/2 and twill 1/7 weaves have the minimum values in the second modulus after fatigue test, respectively.

IV. CONCLUSION

The following results were found from the fatigue tests on the polyester filament woven fabrics under cyclic loading:

Based on the statistical analysis of results, the cyclic loading has not significant effect on the maximum load of fatigued samples. However, the number of cyclic loading has an important effect on the tensile strain of fabrics. In fact the increasing of cyclic loading numbers decreases the value of tensile strain of samples. Also, the number of cyclic loading affects on the second modulus of all samples. Increasing of cyclic loading increases the value of second modulus of fabrics.

The weft density of samples has a significant effect on the maximum load, tensile strain and second modulus of the fatigued fabrics. The value of maximum load, tensile strain and second modulus of fabrics increases with the increasing of weft density.

The stroke level does not significantly affect on the maximum load but it has a significant effect on the tensile strain. The increasing of stroke value causes the decrease in the tensile strain of samples. Also, it has a significant effect on the second modulus. Increasing of stroke value leads to increase in the second modulus of fabrics.

The statistical analysis results show that the fabric structure has the significant influence on the mechanical properties of fabrics in both warp wise and weft wise directions.

Totally, it can be concluded that exertion of cyclic loading on the filament polyester woven fabrics causes the fatigue to fabrics which is very important issue in the application of such materials. Further study is still required to find out an analytical expression between the fabric structure and the mechanical behavior of this type of materials.

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